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CONTROL OF INTERNAL HYDRAULIC FLOW CONDITIONS.

LT. COMMANDER HOWARD L. COOPER, U. S. N. R.

While conducting visual tests on transparent draft tube models for the U. S. Engineers, the author observed many unusual flow conditions, especially when the flow was changing direction. A fluid in a hydraulic turbine draft tube elbow decelerates as it passes through from the turbine through the tube to the tailrace. This form of velocity change adds many problems to the study of flow conditions in all types of bends.

Straight sections of piping offer no serious problems in the control of internal flow condition, except the friction loss and the concentric increase of velocity toward the center of the pipe. Many serious problems and uncontrolled flow conditions are present when a fluid changes direction while being conducted from one location to another in any shape of conduit. Increasing the velocity increases

the disturbance as the flow approaches a critical condition when it goes completely out of control.

Each shape of fitting that is used to change direction or divide the flow is a special problem and should be studied and analyzed individually.

By reversing the flow in draft tubes and accelerating the flow, entirely different characteristics were observed. These variable and unusual characteristics were a prime reason why the author undertook the study and analysis of other forms of bends. Several types of bends were tested and will be discussed separately.

After collecting as much information as was then available, several bends were constructed and tested, both for velocity head drop and general flow characteristics. Some of the bends constructed by other laboratories were obtained and tested in comparison with the new bends that had previously been developed.

Equipment for testing the various bends consisted of a settling tank located about ten feet above the floor, equipped with special baffles so installed that the flow could be shifted from a straight flow to a flow having a forty-five degree whirling component and a series of transparent piping, the same size as the connections to the bends for connecting the tank to the bends, and the bends to a sump, where a pump repumped the water to the overhead settling tank.

Piezometer connections were fastened to the pipe and bends at various locations. From these connections hoses were carried to mercury columns where the changes in head conditions could be accurately measured.

The easiest way to compare the bends with the available testing equipment was to calculate from the test data the loss in velocity head in each of the bends. Although this was not an accurate figure of total loss, it was indicative of the merits and disadvantages of the various bends tested.

Many more complicated combinations can be visualized; for example, where elbows, "Y" branches, tees, manifolds, reducers, and enlargers may all group together in one comparatively short piping system. Naturally the problems become more complicated when the liquid varies in temperature with its corresponding changes in the internal frictional components.

A few installations that could possibly be improved by corrective flow control are:

1. Chemical plants.
2. Machines requiring accurate proportioning of liquids, chemicals, etc.
3. Steam plants.
4. Water works.
5. Most all piping systems on board ship.
6. Pipe line dredging systems.
7. Sea-going dredges.
8. Hydraulic valve control.
9. Hydraulic turbines and water wheels.
10. Wood pulp and paper plants.
11. Manifold systems.
12. Condensers.

Some of the businesses that could improve their products by applying flow control to the equipment being designed and manufactured are:

1. Hydraulic machinery designers and builders.
2. Centrifugal pump manufacturers.
3. Pipe and fitting manufacturers.
4. Turbine and water wheel manufacturers.

The author wishes to show how flow control studies helped solve a problem that had been impossible to accomplish by ordinary design methods. This problem was on a sea-going dredge having two suction lines operating on one electrically-driven dredge pump. The suction lines came through the sides of the ship, where large flexible couplings allowed the suction pipe to move up and down with the change in the depth of the water.

By installation of a standard "Y" connection to the single suction of the pump, both suction lines would not operate continuously at the same time; when one hopper passes over a hard surface and more water is drawn in than when handling a normal amount of water and material, the other side will lose suction. When the suction was lost in this manner, that side would have to be closed and the dredge continue to operate on one line until the pump was stopped and started again with both suction lines open.

A model elbow of conventional design was built, installed on the model pump, and by simulating the actual conditions, one side would also lose its suction.

After watching the flow through this model "Y" branch, it was comparatively easy to see what had to be done so that both lines would function at the same time. A new "Y" branch was built according to the results of the studies made on the standard "Y".

When tested in the model, it was impossible to stop the suction on either of the suction lines when actual dredging conditions were simulated in the laboratory. A prototype was constructed along these designs and when put into operation, the single suction dredge pump operated perfectly when dredging with both suction lines open.

The author could list many examples where practical application of internal flow studies has improved the efficiency and hydraulic operating conditions of machinery and piping systems.

By scientific study and analysis, systems having delicate control requiring accurate distribution can be designed so as to maintain almost perfect control of the liquid at all times.

The author considers this data extremely valuable in the designing of complicated piping systems where distorted flow causes un-uniform distribution and loss of energy, and may be the cause of corrosion and cavitation.

Theory of Induced Spirals in Elbows.

Complications are inherent with the flow of water in any channel where the filaments are forced to undergo a general change of

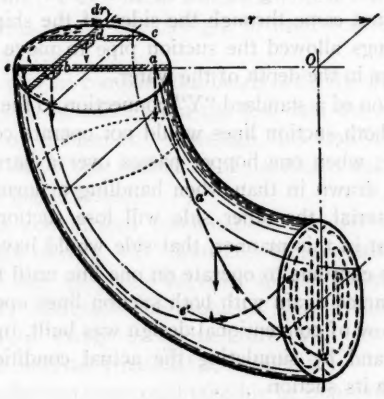

Figure 1.

direction. If there were stream-line flow of equal velocities at the entrance to a bend, and if friction could be eliminated, no complications of any great import would be encountered.

Friction being always present, the filament of flow near the walls of the pipe will be of less velocity than those near the center and as the water enters a bend, a spiral flow is induced automatically. See Figure 1.

As an explanation of the cause of the spiral flow, let a small block of water, b, at a distance, r, from Point O, Figure 1, have unit length and breadth, and a thickness, dr. Its volume then would be infinitesimally small as represented by the expression: $dQ = dr$; and its mass would be,

$$dm = \frac{w}{g} dQ = \frac{w}{g} dr \qquad 1$$

in which w = the weight per unit volume; and g = the acceleration of gravity.

From mechanics it is known that the centrifugal force induced by the liquid moving with a velocity, V, being deflected (formula No. 20) by a circular bend of radius r, is:

$$dF = dm \frac{V^2}{r} = w V^2 \frac{dr}{rg} \qquad 2$$

The area of the side of the small block is unity, since it is of unit length and breadth, and the intensity of pressure, increased on the left side of the small block caused by the centrifugal force is:

$$dp = w V^2 \frac{dr}{rg} \qquad 3$$

If the velocities of the filaments between Points a and b are considered equal, and if the inner radius is designated by ri and the outer radius by ro, the difference in pressure between these limits integrates into the following:

$$\Delta p = w \frac{V^2}{g} \int_{r_i}^{r_o} \frac{dr}{r} = \frac{wV^2}{g} \log \left(\frac{r_o}{r_i} \right) \qquad 4$$

Equation 4 indicates that the difference in pressure caused by the centrifugal force is a function of the square of the velocity.

It is similar to the expression for the impulse, or reaction of a jet of water:

$$F = \frac{WV}{g} \qquad 5$$

in which, F = the force, in pounds; V = the velocity of the jet in feet per second; and W = the flow of water, in pounds per second. The weight, in pounds per second, is then a function of velocity, so that the force, F, is a function of the square of the velocity. Thus it appears logical that as the bend is encountered the pressure either should be increased at Point e (Figure 1), or reduced at Point a by some amount, not necessarily exactly equal to that indicated by Equation 4, because the velocities along the traverse between Points a and e are not all of equal magnitude. These velocities will change as the pressures change in the flow around the bend, and perhaps changes will occur even in advance of the bend.

If all the filamental velocities of the water were equal at the entrance to the bend (a condition which could not be obtained easily without a very special apparatus) the pressure at Point d (Figure 1) would be the same as that at Point b; but, due to the lower velocities in the elementary strip, c—d, the pressure at Point d will be less than that at Point b. Therefore, a transfer of water from Point b toward Point d will tend to take place.

Likewise, movement will tend to occur from Point a toward Point b, and a double spiral is induced. The two principal causes of this condition are:

(1) The centrifugal force in the pipe bend; and (2) the existence of friction on the pipe walls so as to give higher velocities near the center of the pipe than near the walls. Under actual conditions the particles of liquid in a path such as e - e - e, and another particle, such as at Point a, might progress in a path such as a - a - a.

These experiments were undertaken primarily for the purpose of determining the laws governing the change in pressure and velocity in different parts of the flowing stream, as the moving liquid undergoes the transition from motion along a straight path to motion around a curve, and then as it undergoes the opposite transition back to final straight-line motion. Secondarily—to attempt to produce an elbow that would offer less resistance to flow

and change the flow back into a straight line flow with the least amount of disturbance after leaving the bend.

The interval velocities were obtained by means of a calibrated pitot tube inserted through the walls of the transparent elbow. The head drop through the various elbows was used to determine the hydraulic characteristics of each of the bends.

Several types of bends were designed, built and tested. The general equation of continuity of flow of a fluid is:

$$\frac{dp}{dt} + \frac{d(p\,V_x)}{d_x} + \frac{d(p\,V_y)}{d_y} + \frac{d(p\,V_z)}{d_z} = o \qquad 6$$

in which p = density of the fluid; t = element of time; V_X = component of velocity along the X — axis; V_Y = component of velocity along the Y—axis and V_Z = component of velocity along the Z—axis.

The density of the liquid used (water) may be regarded as constant, and the equation of continuity becomes:

$$\frac{d\,V_x}{d_x} + \frac{d\,V_y}{d_y} + \frac{d\,V_z}{d_z} = o = \text{DIVERGENCE} \qquad 7$$

If the motion is irrotational $\delta_x = \frac{2\ \text{Tan}\ \phi\ (V_x)^{2\cdot5}}{r_o\ V_o^{\,0\cdot5}}$ the curl of the velocity vector is zero, and the vector of which V_X, V_Y, and V_Z are components is derivable from a potential.

For irrotational motion, the components of flow in the direction of the axes X, Y, and Z are:

$$V_x = -\frac{d\Psi}{d_x}\ ;\ V_y = -\frac{d\Psi}{d_y}\ ;\ \text{and}\ V_z = -\frac{d\Psi}{d_z}$$

The equation of continuity then becomes:

$$\frac{d^2\Psi}{d_x^2} + \frac{d^2\Psi}{d_y^2} + \frac{d^2\Psi}{d_z^2} = o \qquad 8$$

which is the Laplace equation.

If this is taken as a special case of two-dimensional flow, say, in the X—Y plane, then,

$$\frac{d^2\Psi}{d_x^2} + \frac{d^2\Psi}{d_y^2} = o \qquad 9$$

The real part, X, of any function, $(x + iy)$, of a complex variable satisfies the equation for the velocity potential, and, at the same time, the imaginary part gives the stream function. Assume that:

$$\Psi + i\Phi = (x + iy)^2 = x^2 - y^2 + 2i(xy) \qquad 10$$

Therefore

$$\Psi = x^2 - y^2 \qquad 11$$

and

$$\Phi = 2xy \qquad 12$$

Equations (11) and (12) satisfy the specifications for two-dimensional irrotational flow since the divergence is zero:

$$\frac{d^2\Psi}{dx^2} + \frac{d^2\Psi}{dy^2} = \frac{d^2(x^2 - y^2)}{dx^2} + \frac{d^2(x^2 - y^2)}{dy^2} = 0 \qquad 13$$

To design a pipe bend from this relation and not to take friction into account, of course, would omit an essential factor in the flow of liquid in pipes, but it was deemed desirable to try it and observe the results.

Design Data of the Various Bends.

Bend No. 1 was a standard short radius elbow having a constant cross sectional area. The area being the same as both the entrance and discharge pipes.

Bend No. 2, Figure 2, suitable for a 6-inch pipe was designed more or less by trial, until that shown in Figure 2 was obtained. If the co-ordinates, in inches, of the beginning point, T, were used as (1, 12) instead of the (1, 18), the angle at Point D would become large. To use (0.5, 18) instead of (1, 18) made the width, A—B, rather large and, at the same time, gave a sharper curve near Point A.

To avoid an abrupt angle at Point D, 1 inch was added to each of the $X + Y$ distances to afford an opportunity to smooth out the hyperbolic curves to meet the parallel filamental flow from the 6-inch pipe at the entrance to the bend. The leg length, L, of the pipe thus became 15 inches as shown in Figure 2.

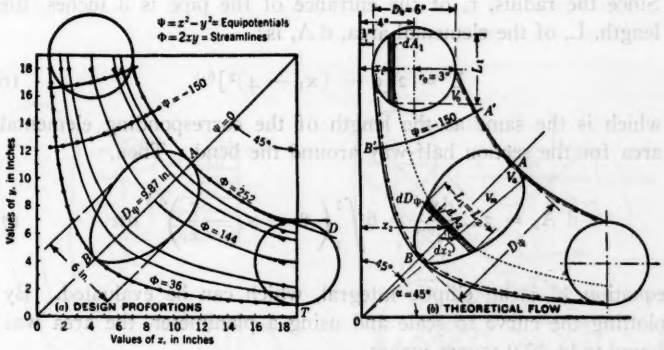
Ψ = x² − y² = Equipotentials
Φ = 2xy = Streamlines
Values of y, in Inches
Values of x, in Inches
(a) DESIGN PROPORTIONS
(b) THEORETICAL FLOW

FIGURE 2.

The distance across the pipe from sidewall to sidewall measured along the equi-potential lines is expressed by the equation

$$D\Psi = \int \left[1 + \left(\frac{dy}{dx} \right)^2 \right]^{0.5} dx \qquad 14$$

Since $x^2 - y^2 = C$ = a Constant; $2x\,dx - 2y\,dy = 0$;

$$\frac{dy}{dx} = \frac{x}{y}\text{; and } \left(\frac{dy}{dx} \right)^2 = \frac{x^2}{y^2}$$

$$D\Psi = \int \left[1 + \left(\frac{x^2}{y^2} \right)^2 \right]^{0.5} dx \qquad 15$$

when $x^2 - y^2 = \Psi = 0$ (which is the special case half-way around the bend), $D\Psi = 9.87$ in.

The area of the cross section of the pipe half-way around the bend Figure 2 may be expressed mathematically assuming, for example, $xy = 18 = C$. Then $x_1 = \frac{C}{18}$. At the 45 degree section, $x = y$, so that $(x_2)^2 = C = 18x_1$. Then $x_2 = 3(2)^{0.5}(x_1)^{0.5}$;

$$dx_2 = \left(\frac{3}{2} \right)(2)^{0.5} \frac{dx_1}{x_1^{0.5}}\text{; } dD\Psi = dx_2\,(2)^{0.5} = 3\frac{dx_1}{x_1^{0.5}}\text{;}$$

$$\text{and, } dA_2 = L\,dD\Psi = 3L\frac{dx_1}{x_1^{0.5}}$$

Since the radius, r, of the entrance of the pipe is 3 inches, the length, L, of the elemental area, d A, is:

$$L = 2[9 - (x_1 - 4)^2]^{0.5} \qquad 16$$

which is the same as the length of the corresponding elemental area for the section half-way around the bend. Then,

$$d A_2 = 3L \frac{dx_1}{x_1^{0.5}} = 6\int_1^7 \left(8 - x_1 - \frac{7}{x_1}\right)^{0.5} dx_1 \qquad 17$$

equation 17 is an elliptic integral, which can be evaluated. By plotting the curve to scale and using a planimeter, the area was found to be 47.0 square inches.

Bend No. 3, Figure 3, with sidewalls defined by the cubic equation

$$y = x - \frac{x^3}{a^2} \qquad 18$$

was also designed and tested. This curve has a slope of 45 degrees at the origin and its horizontal at its maximum point where $X = a$, and $Y = \frac{2a}{3}$. The radius of curvature is infinity at the origin, and is 0.5 a at the maximum point.

The part of the curve between the origin and the maximum point was used to make one-half the bend; and then it was turned over to make the other half of the bend as shown in Figure 3.

By assuming values of a in Equation (18), the sidewalls of the bend were obtained. This bend would always bulge at the vertex. The final dimensions of the bend, as adopted for testing, had a diameter at the vertex of 7.06 inches, an entrance diameter of 6 inches, and a leg length of 15 inches. This was obtained by taking values of a for the inside wall, the axis, and the outside wall, equal to 7.88, 10, and 12.12, inches, respectively. By using these values of a the leg length would have become 14.14 inches, but this was arbitrarily increased to 15 inches, making the additional leg length have parallel sidewalls as in a 6-inch cylinder. Hereafter, this pipe bend will be designated as Bend No. 3.

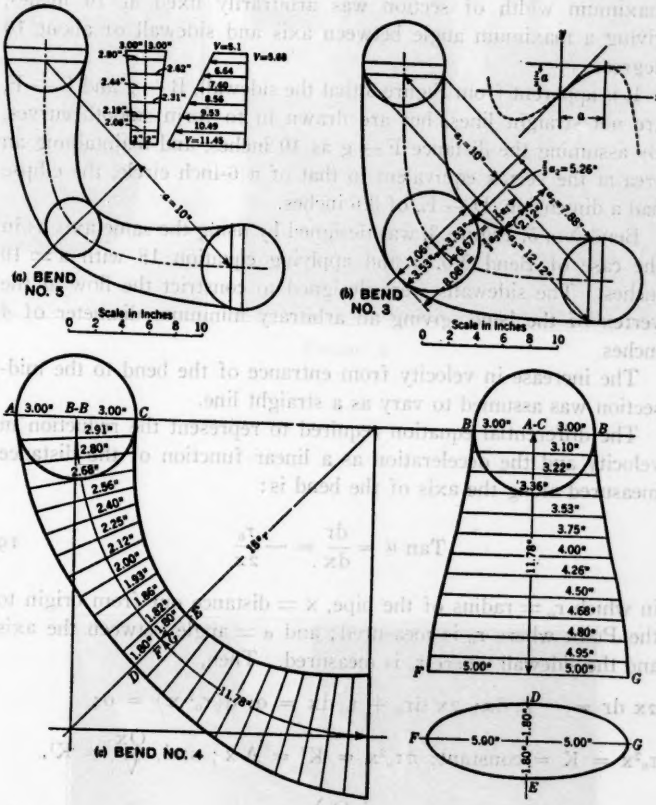
(a) BEND NO. 5
Scale in Inches
0 2 4 6 8 10
(b) BEND NO. 3
Scale in Inches
0 2 4 6 8 10
(c) BEND NO. 4
A
B-B
C
D
A-C
B
F
G
E
5.00"
11.78"
18"

FIGURE 3.

Bend No. 4, Figure 3, was designed and built having all cross-sections elliptical and of equal area. The axis of the bend was a quadrant with a radius of 15 inches, as shown in Figure 3. The maximum width of section was arbitrarily fixed at 10 inches, giving a maximum angle between axis and sidewall of about 10 degrees.

It is apparent from Figure 3 that the sidewall, B — g and B — F, are not straight lines, but are drawn in to form smooth curves. By assuming the distance F — g as 10 inches, and maintaining an area at the vertex equivalent to that of a 6-inch circle, the ellipse had a dimension, D — E, of 3.6 inches.

Bend No. 5, Figure 3, was designed by using the same axis as in the case of Bend No. 3 and applying equation 18 with $a = 10$ inches. The sidewalls were designed to constrict the flow at the vertex of the bend, giving an arbitrary minimum diameter of 4 inches.

The increase in velocity from entrance of the bend to the mid-section was assumed to vary as a straight line.

The differential equation required to represent the reduction in velocity and the deceleration as a linear function of the distance measured along the axis of the bend is:

$$\text{Tan } \alpha = \frac{dr}{dx} = -\frac{r_o}{2x} \qquad 19$$

in which r_o = radius of the pipe, x = distance out from origin to the Point where r_o is measured; and α = angle between the axis and the sidewall where r_o is measured. Then,

$$2x\,dr = -r_o\,dx;\quad 2x\,dr_o + r_o\,dx = o;\quad d(r_o^2\,x) = o;$$

$$r_o^2 x = K = \text{constant};\quad \pi r_o^2 x = K^1 = A\,x;\quad \text{and,}\quad \frac{Qx}{V} = K^1.$$

$$\text{Therefore } V = \left(\frac{Q}{K^1}\right) x \qquad 20$$

which represents a straight line.

If the velocity is differentiated with respect to time, the result will be deceleration; thus:

$$\frac{dV}{dt} = \left(\frac{Q}{K^1}\right)\frac{dx}{dt} = \left(\frac{Q}{K^1}\right) V \qquad 21$$

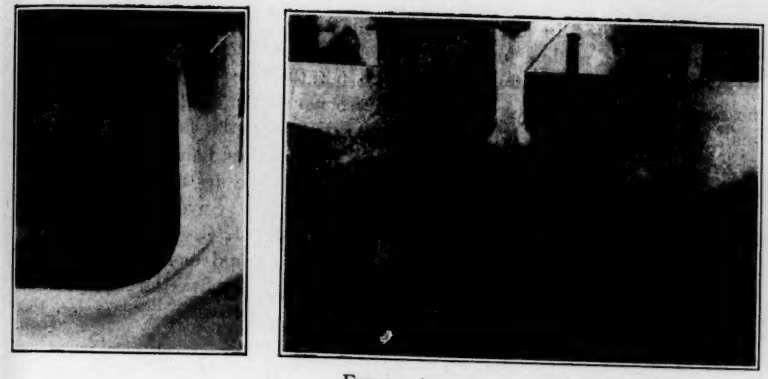

FIGURE 4.

FIGURE 5.

This again is a linear equation in X, since $\frac{dx}{dt}$ is velocity. The velocity variation from the entrance to the midpoint of this bend is shown in Figure 3 for a special case, in which the rate of flow is 1.0 cubic feet per second.

Construction of bends.—All the bends were constructed of pyralin heated and pressed into the desired shapes by means of wooden forms. Sections and pitot tube fittings were fastened together with ordinary acetone.

Loss of head in the several bends expressed in terms of the velocity head and exclusive of frictional resistance was as follows:

Bend No. 1	$0.15\frac{V^2}{2g}$
Bend No. 2	$0.15\frac{V^2}{2g}$
Bend No. 3	$0.17\frac{V^2}{2g}$
Bend No. 4	$0.13\frac{V^2}{2g}$
Bend No. 5	$0.16\frac{V^2}{2g}$

Visual Results of the Tests.

Bend No. 1. The slow motion camera definitely showed the double spiral forming in the center of this bend and complete when the liquid started to enter the straight section of pipe. This disturbance did not straighten out into concentric flow until the flow had reached a point about 15 to 20 diameters from the bend.

Bend No. 2. Figure 2. This hyperbolic bend definitely showed a multiplicity of currents and eddies with no continuity of flow, definitely indicating that it is of no value as an efficient elbow.

Bend No. 3. Figure 3. The flow in the cubical bend was about the same as Bend No. 2.

Bend No. 4. Figure 3. This bend showed a definite improvement in flow conditions, not only was the velocity head loss approximately 15 per cent less than Bend No. 1 and No. 2 and 30 per cent less

than Bend No. 3, but the flow returned to its original flow characteristics in ⅓ to ½ the distance of the other bends.

Analyzing this bend in more detail indicates that the double spirals could not develop as completely as they did in the other type bends. The flattened section at the center of the bend tended to resist the forming of the double spiral and no doubt was responsible for reducing the disturbance and the losses.

Project a stream of water on a curved plane Figure 4 and it is easy to visualize that the natural tendency of a liquid when changing direction is to form a thin fan-shaped stream. If this flat stream of water is in a confined ordinary elbow, Figure 5, it can be easily seen how the double spiral is formed by the flat stream folding over on itself.

The author believes that this design is a move in the right direction and no doubt could be improved by additional studies of modified shapes.

Bend No. 5. Figure 3. This bend showed a smooth continuity of flow until the liquid started to decelerate, when it became violently disturbed. Apparently the angle of divergence of the sidewalls was too large to insure smooth deceleration.

This brings up a point that may be of considerable value in bend design when it is necessary to eliminate disturbances in adjoining sections.

A TEMPERATURE-ENTROPY DIAGRAM FOR AIR BASED ON SPECTROSCOPIC SPECIFIC HEATS.

By Lieutenant F. C. Marggraff, Jr., U.S.N.* (Retired.)

and

Arthur H. Senner.†

The basic differential equation from which the temperature-entropy diagram is computed, can be written: $ds = \frac{dQ}{T}$, (1) and if one is interested in preparing a simple chart consisting of a family of constant pressure curves, such as will be discussed in this paper, the equation can also be written, $ds = \frac{C_p dT}{T}$, (2) in which,

S = entropy, Btu. per pound × degree F.

Q = heat added, along a reversible path, Btu. per pound.

T = absolute temperature, degree R.

C_p = specific heat at constant pressure, Btu. per pound per degree F.

Development of the differential equation connecting entropy, temperature and heat added, is presented in standard thermodynamics texts, and is no doubt familiar to most readers. It is perhaps sufficient to point out that integration of equation (2) will give an expression for change of entropy at constant pressure, with reference to some chosen datum of temperature, in our example to be taken at zero Fahrenheit. Since entropy is also a function of pressure of the medium, some datum of pressure must also be selected, and this will be chosen as 10 psi absolute. These

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choices are arbitrary—in engineering we are invariably interested in changes of entropy rather than in absolute values, and for this reason the datum values of temperature and pressure may be chosen at will. The quadrature expressing change of entropy from equation (2) is $\triangle S = \int_{T_1}^{T_2} Cp \frac{dT}{T}$. If the specific heat is assumed to be constant, the integration is very simple. However, the specific heat of air varies appreciably with change in temperature and also to some slight extent with change in pressure; the latter effect is so small within the range of pressure in which we are interested for the present, that it will be neglected.

It is the purpose of this paper to construct, from the latest specific heat data, a temperature—entropy diagram for air, extending through a pressure range of 5 to 100 psi absolute, and a temperature range of 80 to 2000 degrees F. and to compare such entropy values with other accepted values. The so-called spectroscopic specific-heat data will be employed; this material has been discussed by R. C. H. Heck under the title, "The New Specific Heats", in the January, 1940, and February, 1941, issues of Mechanical Engineering. To permit integration of equation (2), C_p must be expressed as a function of temperature and recourse was had to the Sweigert and Beardsley empirical specific-heat equations, based on the spectroscopic data, and published in Bulletin No. 2, 1938 of the State Engineering Experiment Station, Georgia School of Technology. The authors do not present specific heat equations for air but they do give them for oxygen and nitrogen, from which a combined equation for air has been computed by Prof. J. C. Smallwood of the Johns Hopkins School of Engineering, from consideration of the relative molal contents of oxygen and nitrogen in air. In this computation, air was assumed to be composed of 1 mol of oxygen and 3.78 mols of nitrogen. On this basis Professor Smallwood derived the following expression for the molal specific heat of air:

$$mCp = 9.9 - 36T^{-\frac{1}{2}} - 2420\,T^{-1} + 917000\,T^{-2}, \quad (3)$$

and similarly the specific heat for air at constant pressure, on a pound basis, is,

$$Cp = 0.341 - 1.241\,T^{-\frac{1}{2}} - 83.585\,T^{-1} + 31632\,T^{-2}, \quad (4)$$

Equation (4) is obtained by dividing equation (3) by 29, the "apparent" molecular weight of air.

Referring back to equation (2), we are now in a position to integrate after substituting expression (4). Having chosen 10 psi absolute pressure and zero Fahrenheit as the datum points of entropy, that is, the zero point, we are now able to determine the value of the definite integral which results from the integration of equation (2) after substituting the expression for C_p as a function of absolute temperature. The increment of entropy at constant pressure, develops into the following expression:

$$(\triangle S)_p = 0.341 \log_e \frac{T_2}{T_1} - 2.482 \left[\frac{T_2^{\frac{1}{2}} - T_1^{\frac{1}{2}}}{(T_1 T_2)^{\frac{1}{2}}}\right] - 83.585 \left[\frac{T_2 - T_1}{T_1 T_2}\right] + 15816 \left[\frac{T_2^2 - T_1^2}{(T_1 T_2)^2}\right], \quad (5)$$

It is to be noted that this expression for $\triangle S$ is at constant pressure condition, and will yield only one of the family of pressure curves which we desire. To obtain the characteristic for successive constant pressure lines, the relation: $(\triangle S)_T = \frac{R}{778} \log_e \frac{P_2}{P_1}$, (6) is employed. This is the perfect-gas expression for change of entropy, with change in pressure, but with temperature constant. In equation (6) the symbols are as follows:

$\triangle S$ = change in entropy due to change in pressure, at constant temperature.

R = gas constant = 53.3 for air.

P_2 = final pressure.

P_1 = initial pressure; and 778 the foot-pound equivalent of a Btu.

By the application of equations (5) and (6) throughout the desired ranges of temperature and pressure, the family of curves of Figure (1) are developed. The range in temperature is from 80 to 2000 degrees F. and from 5 to 100 psi absolute pressure. The empirical specific heat equations do not hold for temperatures less than 80 degrees F., therefore the temperature-entropy diagram is limited to that lower temperature. This range, for ex-

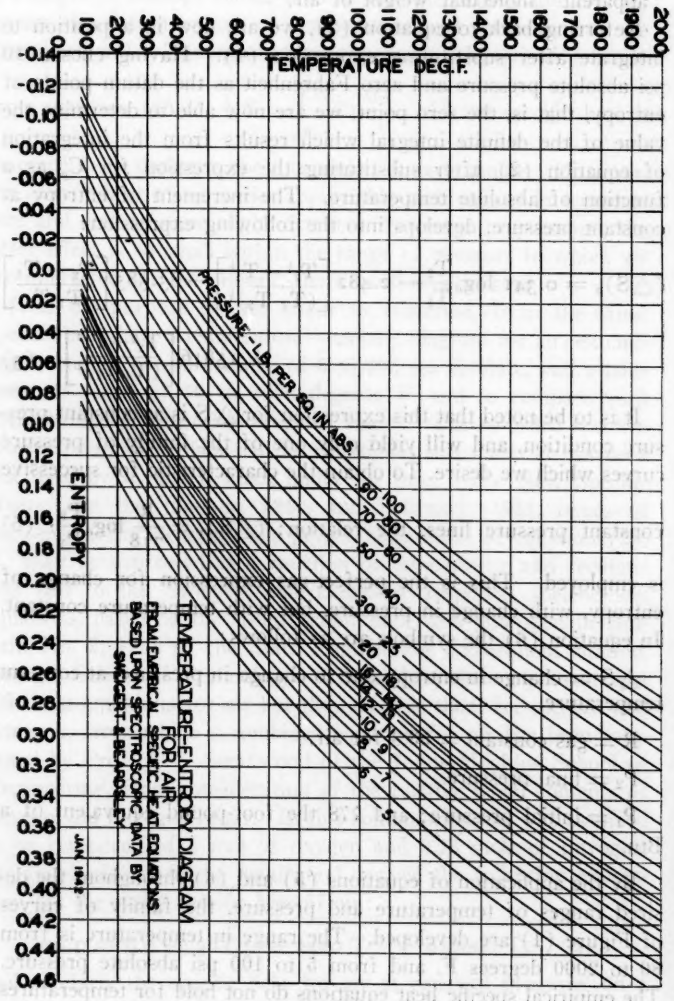
TEMPERATURE DEG. F.
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
ENTROPY
0
-0.14
-0.12
-0.10
-0.08
-0.06
-0.04
-0.02
0.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46
PRESSURE - LB. PER SQ. IN. ABS.
100
90
80
70
60
50
40
30
25
20
18
16
14
12
10
9
8
7
6
5
TEMPERATURE-ENTROPY DIAGRAM
FOR AIR
FROM EMPIRICAL SPECIFIC HEAT EQUATIONS
BASED UPON SPECTROSCOPIC DATA BY
SWIGERT & BEARDSLEY
JAN. 1942

FIGURE 1.

ample, is ample to include the terminal state points of certain gas turbine cycles. The family of curves in Figure (1) check fairly well with the corresponding entropy material based on the frequently quoted Partington and Shilling specific heat data, up to about 600 degrees F. Above that temperature, the curves of Figure (1) are less steep, that is, the entropy values are relatively larger than those based on Partington and Shilling.

A comparison of the entropy values for air based on the spectroscopic specific heats and those based on the Partington and Shilling values is given in the following tabulation. The zero of entropy for both cases is at zero degrees Fahrenheit temperature and 100 psi absolute pressure.

Temperature, Deg. Fahr.	Entropy Values at 100 psi absolute pressure	
	Based on Partington and Shilling Specific Heats	Based on Spectroscopic Specific Heats.
200	—0.070	—0.070
400	—0.007	—0.007
600	0.045	0.045
800	0.087	0.090
1000	0.125	0.128
1200	0.157	0.163
1400	0.185	0.194
1600	0.212	0.222
1800	0.236	0.249

Similar tabulations could be made for other pressures but the above will serve to show the trend of difference between the entropies based on spectroscopic specific heats and those based on Partington and Shilling values for example. Up to about 600 degrees F., the entropies are the same; above that temperature the spectroscopic values are greater than those based on Partington and Shilling. At the 1800 degree level the former value is about 6 per cent greater than the latter.

OVERALL BOILER EFFICIENCY DETERMINATIONS BY THE DIFFERENCE METHOD.

By SAMUEL LETVIN *

One of the objectives in boiler test work and an index to operation is the overall efficiency, that is, per cent of Btu. absorbed relative to Btu. fired. Determination of boiler overall efficiency requires not only readily obtainable temperatures and flue gas analysis but fuel and water rates. Unless a plant is especially equipped, quantities of water and fuel going to the boiler cannot be determined with any reasonable degree of accuracy. This article, complete with charts and log sheet, outlines a short method of approximating overall boiler efficiency without knowledge of water or fuel rates. Such a method will be found useful on trials during design and layout work where a good approximation of boiler efficiency is required. This procedure of determining boiler efficiency is known as the "difference" method and can be expressed by the following equation:

Overall Efficiency per cent =
100 per cent—(Total Boiler Losses per cent) or
100 per cent—(Moisture Loss Stack Gases per cent)—(Dry Gas Stack Loss per cent)—(Unaccounted-for and Radiation Loss per cent)

Computation of boiler efficiency by the "difference" method requires the following operating data:

(1) Specific gravity of the fuel oil. From the specific gravity the calorific value of the fuel can be estimated, also the theoretical air required by the fuel, the weight of moisture from the burning of the hydrogen in the fuel, and the identity of the oil in terms of its maximum CO_2 (complete combustion with theoretical air) for determination of excess air.

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(2) Temperature of stack gases, CO_2 in the stack gases, and air temperature at the boiler entrance.

With the above data taken during a steady steaming period and an evaluation for the "unaccounted-for and radiation losses" as given by Item 12 on the sample log sheet, the overall boiler efficiency can be obtained. The "unaccounted-for and radiation loss" data given on the sample log sheet are based on average values of many boilers tested at the Naval Boiler and Turbine Laboratory and numerous boiler tests conducted elsewhere. The "unaccounted-for and radiation losses" may be considered similar to experimental values of coefficients which are applied to orifices as they both show a difference between theoretical and actual values. This heat loss represents a difference between the heat absorbed, the determination of which can be very accurate, the sum of combustible, radiation, and the calculated heat losses, of which the latter are more prone to error since they are evaluated from instruments and data which endeavor to effect a true average of the stack temperature and CO_2. The design of the boiler and uptakes usually affects the distribution of stack gases. Thus, the "unaccounted-for and radiation losses" for boilers of different designs can be quite dissimilar. Air-encased boilers naturally have the lowest radiation loss. Steam generators with cold furnaces, such as Scotch boilers, will have relatively high combustible losses.

For purposes of illustration, a complete calculation is shown below using the log sheet and the data contained in Charts A and B. Assume that the boiler under test is a Naval express A type boiler (closed fireroom) and is operating with 14.0 per cent CO_2, 380 degrees F. stack temperature, and air inlet temperature of 100 degrees F. (Items 6, 7, and 8 respectively), and the fuel being fired has a specific gravity of 0.975 (Item 1). Chart A, using the specific gravity of the oil, provides the fuel characteristics, Items 2 to 5, inclusive, of the log sheet. These values are based on data of approximately 300 different fuel oil tests, expressed empirically, covering a wide range of fuels. Chart B gives the excess air (Item 9) being used and is based on the CO_2 in the flue gas taken during the run. The maximum CO_2 lines on Chart B identify the fuel being fired and are a function of the specific gravity of the fuel.

BOILER EFFICIENCY CALCULATION FORM

DATE_____ BOILER_____

RUN NO._____ TIME FROM_____ TO_____

ITEM NO.	ITEM	FORMULA AND CALCULATIONS	RESULT
	FUEL CONSTANTS (FROM CHART A)		
1	SPECIFIC GRAVITY OF FUEL	60°/60°F.	.975
2	CALORIFIC VALUE	B.T.U./LB.	18,500
3	HYDROGEN CONTENT OF FUEL	%	10.7
4	THEORETICAL DRY AIR REQUIRED FOR COMBUSTION OF 1 LB. OF FUEL	LBS./LB.	13.73
5	WEIGHT OF MOISTURE FROM BURNING HYDROGEN	0.09×[3] = 0.09×(10.7) LBS./LB.	.963
	VARIABLES (FROM TEST DATA)		
6	CARBON DIOXIDE	%	14.0
7	TEMPERATURE OF GASES LEAVING BOILER	°F.	380
8	AIR TEMPERATURE AT BOILER ENTRANCE	°F.	100
9	EXCESS AIR (FROM CHART B—USING ITEMS 1 AND 6)	%	14.0
	CALCULATIONS		
10	MOISTURE LOSS—%	$[1080+0.46([7]-[8])]\times[5]\times\frac{100}{[2]}$ $[1080+0.46(380-100)]\times(.963)\times\frac{100}{(18,500)}$	6.1
11	DRY GAS LOSSES—%	$[2]\times\left(\frac{[6]}{[6]+[9]}\right)\times[1-5]\times 0.25\left([7]-[8]\right)\frac{100}{[2]}$ $[0.373\times\left(\frac{14.0}{14.0+14.0}\right)\times(1-.963)]\times 0.25\left[(380-100)\right]\frac{100}{(18,500)}$	5.9
12	U AND R LOSS—%	10% NAVAL EXPRESS M TYPE BOILERS (AIR ENCASED) 10% NAVAL EXPRESS A TYPE BOILER (AIR ENCASED) 15% NAVAL EXPRESS A TYPE BOILERS (CLOSED FIREROOM) 20% "D" TYPE MERCHANT MARINE BOILERS 15% SECTION HEADER BOILERS 30% SCOTCH MARINE BOILERS	1.5
13	OVERALL BOILER EFFICIENCY %	$100-[11]+[12]$ $100-[6.0+5.9+1.5]$	84.5

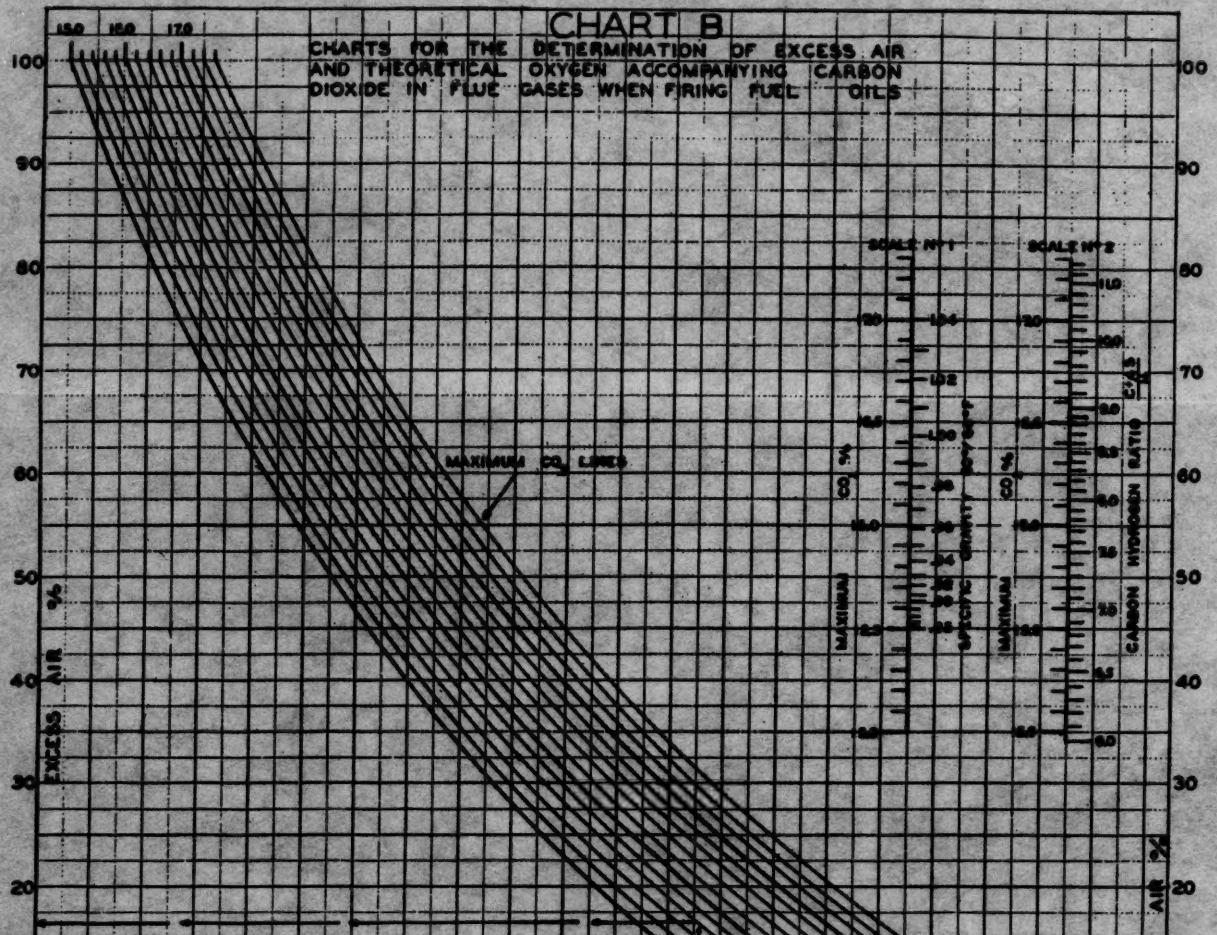
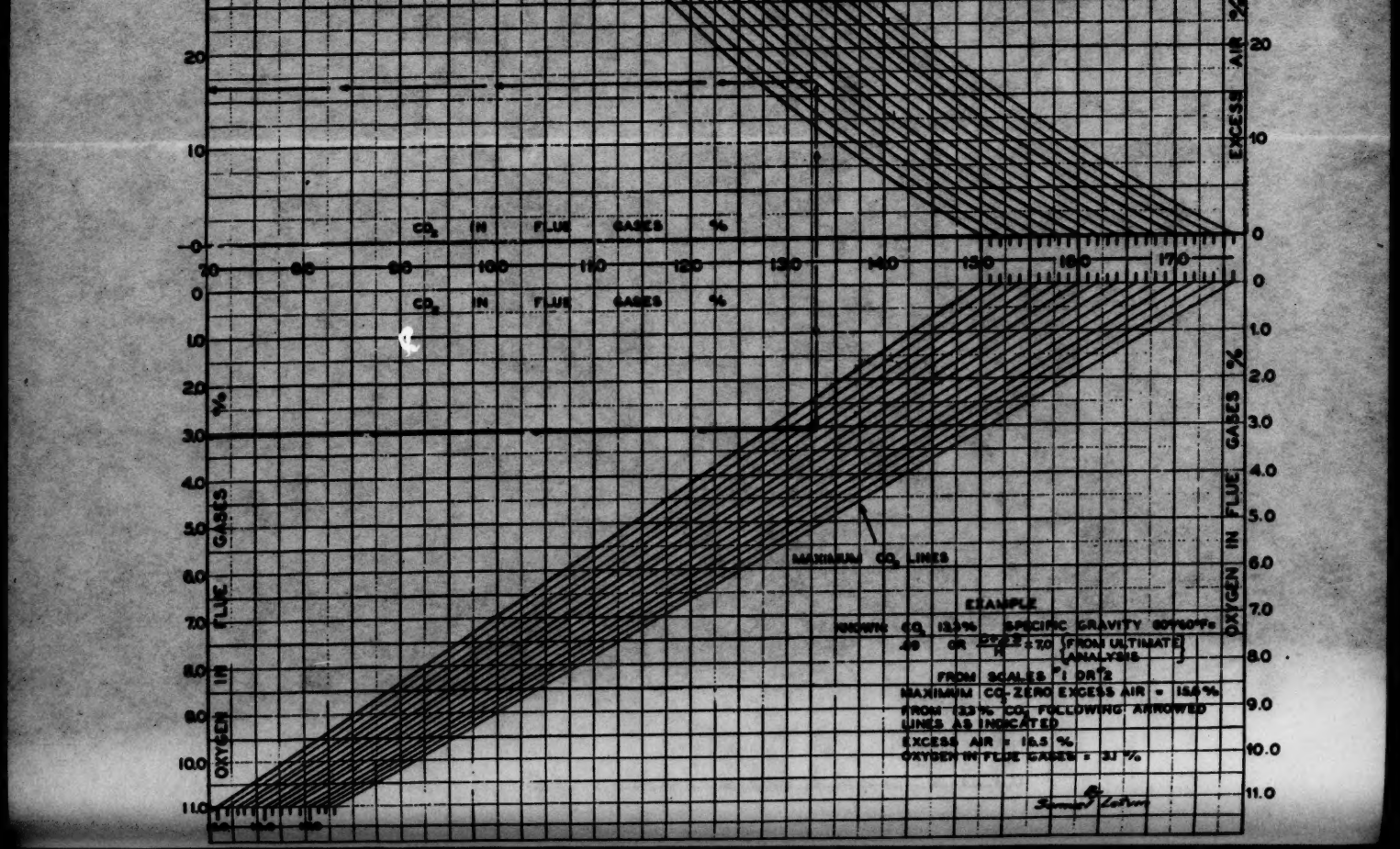


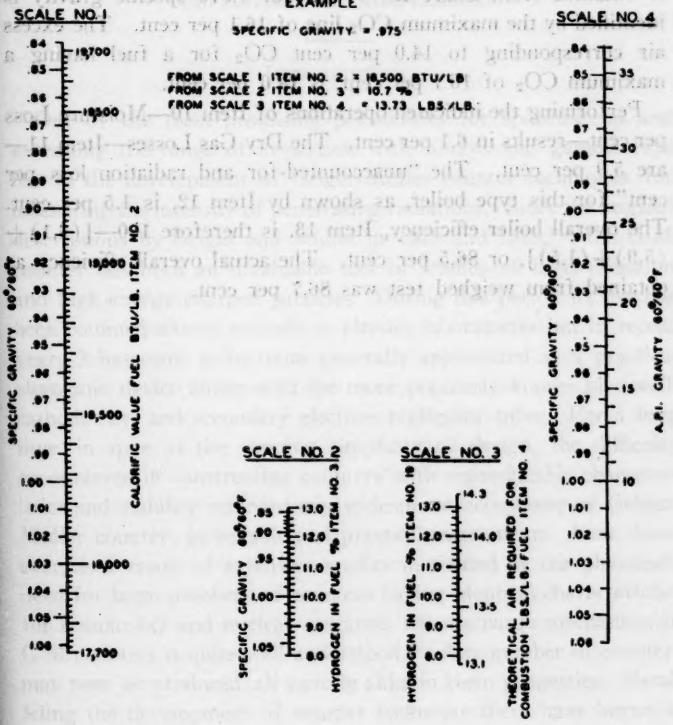
CHART B
CHARTS FOR THE DETERMINATION OF EXCESS AIR AND THEORETICAL OXYGEN ACCOMPANYING CARBON DIOXIDE IN FLUE GASES WHEN FIRING FUEL OILS
150
160
170
MAXIMUM CO2 LINES
EXCESS AIR %
SCALE N°1
SCALE N°2
CO2 %
MAXIMUM
SPECIFIC GRAVITY 60°F
CARBON HYDROGEN RATIO
C/H
THEORETICAL AIR %


CO2 IN FLUE GASES %
CO2 IN FLUE GASES %
MAXIMUM CO2 LINES
EXCESS AIR %
OXYGEN IN FLUE GASES %
EXAMPLE
KNOWN: CO2 13.3%
AND CR 27.22 ÷ 2.0 (FROM ULTIMATE ANALYSIS)
SPECIFIC GRAVITY 60°/60°F.
FROM SCALES F1 OR F2
MAXIMUM CO2 ZERO EXCESS AIR = 15.4%
FROM 13.3% CO2 FOLLOWING ARROWED LINES AS INDICATED
EXCESS AIR = 16.5 %
OXYGEN IN FLUE GASES = 3.1 %

SPECIFIC GRAVITY 60°/60°F

CHART A

REQUIRED PARTICULARS OF FUEL OIL BASED ON SPECIFIC GRAVITY NECESSARY FOR HEAT BALANCE EVALUATIONS


EXAMPLE
SPECIFIC GRAVITY = .975
FROM SCALE 1 ITEM NO. 2 = 18,500 BTU/LB
FROM SCALE 2 ITEM NO. 3 = 10.7 %
FROM SCALE 3 ITEM NO. 4 = 13.73 LBS./LB.
SCALE NO. 1
SPECIFIC GRAVITY 60°/60°F
CALORIFIC VALUE FUEL BTU/LB. ITEM NO. 2
SCALE NO. 2
SPECIFIC GRAVITY 60°/60°F
HYDROGEN IN FUEL % ITEM NO. 3
SCALE NO. 3
HYDROGEN IN FUEL % ITEM NO. 3
THEORETICAL AIR REQUIRED FOR COMBUSTION LBS./LB. FUEL ITEM NO. 4
SCALE NO. 4
SPECIFIC GRAVITY 60°/60°F
A.P.I. GRAVITY 60°/60°F

Therefore from Chart A the calorific value of the fuel, the hydrogen content, and the dry air theoretically required for the combustion of one pound of fuel are 18,500 Btu. per pound, 10.7 per cent, and 13.73 pounds per pound, respectively. These values are Items 2 to 4. The weight of moisture (Item 5) is obtained by multiplying the percentage of hydrogen in the fuel by .09 (9 pounds of water result from the combustion of one pound of hydrogen). The percentage of excess air (Item 9) is obtained from Chart B. A fuel of 0.975 specific gravity is identified by the maximum CO_2 line of 16.1 per cent. The excess air corresponding to 14.0 per cent CO_2 for a fuel having a maximum CO_2 of 16.1 per cent, is 14.0 per cent.

Performing the indicated operations of Item 10—Moisture Loss per cent—results in 6.1 per cent. The Dry Gas Losses—Item 11—are 5.9 per cent. The "unaccounted-for and radiation loss per cent" for this type boiler, as shown by Item 12, is 1.5 per cent. The overall boiler efficiency, Item 13, is therefore 100—[(6.1)+(5.9)+(1.5)], or 86.5 per cent. The actual overall efficiency as obtained from weighed test was 86.7 per cent.

APPLICATIONS OF GEIGER-MULLER COUNTERS TO INSPECTION WITH X-RAYS AND GAMMA RAYS†.

By Herbert Friedman*, Herman F. Kaiser* and Arthur L. Christenson*.

Introduction.

One of the most promising possibilities for speeding up and extending the range of inspection with X-rays and gamma rays lies in the development of Geiger-Muller counter techniques for measuring the intensity of penetrating radiations. Since the original descriptions by Geiger and Muller in 1928 and 1929,[1] the G-M counter has been an invaluable tool in studies of hard radiation and high energy charged particles. During this period its use has been confined almost entirely to physics laboratories but in recent years it has come to be more generally appreciated as a practical electronic device along with the more popularly known photocell, cathode ray, and secondary electron multiplier tubes. For a long time, in spite of the seeming simplicity of design, the difficulty encountered in constructing counters with reproducable characteristics and stability retarded any widespread acceptance of Geiger-Muller counters as reliable and practical instruments. Now, however, as a result of extensive studies motivated by the physicist's need for large numbers of counters having identical characteristics for cosmic ray and nuclear research, the discharge mechanism in G-M counters is quite well understood.[2] Any number of counters may now be produced, all exactly alike in their properties. Paralleling the development of counter technique there have begun to appear numerous applications of counters to industrial problems, as well as to other fields of scientific research.

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† Published by permisison of the Navy Department.

Practically all non-destructive testing with penetrating radiations, utilizes photographic film or fluorescent screens to indicate transmitted intensity. Because such radiation is very weakly absorbed in a photographic emulsion the absolute efficiency of the photographic method of registering intensity is necessarily low. For example, with standard X-ray equipment generating 300 Kv. X-radiation, the practical limit for exposure time permits the radiography, at best, of about four inches of steel. With strong sources of radium, it is possible to penetrate greater thicknesses but this is accomplished at the expense of much longer exposures. The radiographing of six inches of steel at eighteen inches source to film distance would require about eight hours with as intense a source as 500 milligrams of radium. There is very slight hope of increasing the speed of the photographic method by any larger factor. Any great gains in efficiency must come through the development of electrical methods and of these, the Geiger-Muller counter applications offer most likelihood of success.

The G–M. counter is by far the most sensitive of all devices for detection of individual charged particles and quanta of radiation. So great is its internal amplification that a single electron suffices to trigger a flow of charge of as many as ten billion electrons. This triggering electron may enter the counter directly, or appear as an X-ray or gamma ray secondary (photoelectric ejection and Compton effect), or as the product of corpuscular ionization due to energetic charged particles. The ability of the counter to respond so strongly to very weak intensities of electromagnetic and corpuscular radiation exceeds the response of any photographic emulsion by many orders of magnitude. In attempting to utilize this sensitivity of the G-M counter for speeding up inspection, three types of application have been developed. To begin with, in the simplest adaptation, it may be employed as an aid to the photographic method, i.e., as an X-ray or gamma ray exposure meter to predetermine correct exposure time for any given radiographic set-up. Secondly, the counter may be used as a follow-up method, for example, to obtain quantitative information as to the magnitude and depth location of a given defect after it has been discovered photographically. Finally, the counter may replace the

film entirely. Inspection is then performed by scanning the surface of the test object at a rate determined by the desired defect sensitivity.

A typical G-M counter (Figure 1) consists of an anode wire, surrounded by and insulated from a cylindrical cathode. Normally, the tube is filled with gas to less than atmospheric pressure, and a potential difference of the order of 1000 volts is applied to the electrodes as shown in the diagram. This voltage is somewhat less than that which would cause a spontaneous electrical discharge to set in between the wire and cylinder. However, all that is needed to trigger such a discharge, is that a single X-ray or gamma ray quantum be absorbed in the gaseous volume. The discharge, once started, is automatically cut off very quickly.

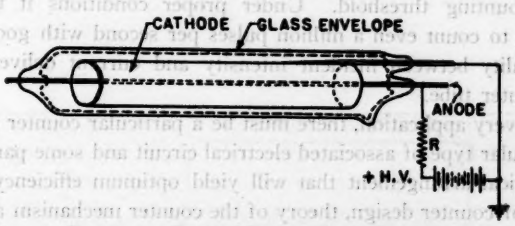

FIGURE 1.—GEIGER-MULLER TUBE COUNTER.

In comparing intensities of penetrating radiations with a G-M counter, one observes the number of discharge pulses per unit time. The ratios of these counting rates are then taken as the ratios of the intensities. The accuracy of these measured ratios is determined entirely by the total number of pulses counted in each measurement, since the emission and absorption of X-ray or gamma ray quanta are random processes. According to the laws of probability, 4300 counts give the intensity with a probable error of 1 per cent but 430,000 are required for 0.1 per cent. Obviously, rapid measurement with high precision calls for the highest possible counting rates.

The time that elapses between the triggering of a discharge and the return of the counter to a condition where it can again register an ionization by a primary ray is called the "resolving time" of the counter. The resolving time of the original counters was of

the order of 0.01 second, which set a limit of less than 100 counts per second for the maximum counting rate. Actually because of the randomness of the production of counts, it was impractical to count more than ten per second, and to obtain a good mean value for the measured intensity, several minutes of counting were required. Fortunately, in recent years, it has become possible to construct counters and electrical circuits for use with counters, having combined resolving times between 10^{-4} and 10^{-5} seconds. With normal counter technique it is now possible to count thousands of quanta per second without excessive losses. In cases where the available intensity is high enough to produce more than 10,000 quantum absorptions per second in the counter, methods have been developed for working at voltages slightly below the G-M counting threshold. Under proper conditions it is then possible to count even a million pulses per second with good proportionality between incident intensity and current delivered by the counter tube.

For every application, there must be a particular counter design, a particular type of associated electrical circuit and some particular geometrical arrangement that will yield optimum efficiency. The details of counter design, theory of the counter mechanism and the circuits designed for operation with counters will be treated in the appendix following the discussion of counter applications.

X-Ray and Gamma Ray Exposure Meter.

To interpret radiographs properly, it is essential that the photographic density be correct. It is general practice among radiographers to determine exposure times from standard technique charts for X-ray radiography, and from the gamma ray radiography slide rule when using radium. For X-ray radiography the technique charts are incomplete and somewhat unreliable. The great dependence of X-ray absorption on the voltage applied to the tube and on the thickness, density, and atomic number of the specimen material, makes it difficult to pick proper exposures, especially for sections of varying thickness and for alloy compositions for which complete calibration data are not available. For these reasons, an X-ray exposure meter has been designed which

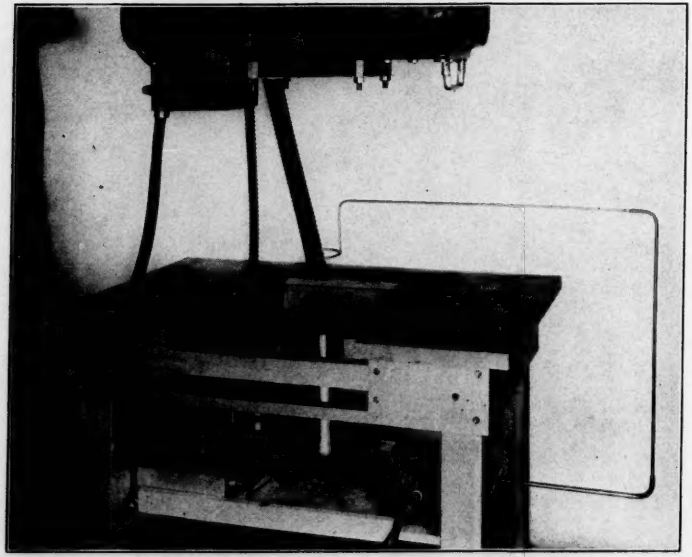

FIGURE 2.—X-RAY EXPOSURE METER APPARATUS. X-RAY TUBE IS LOCATED IN CASE AT TOP OF PHOTOGRAPH. SPECIMENS ARE PLACED ON MASK AND FILM CASSETTE SLIDES UNDER SPECIMEN ON DRAWER NOT SHOWN IN PHOTOGRAPH.

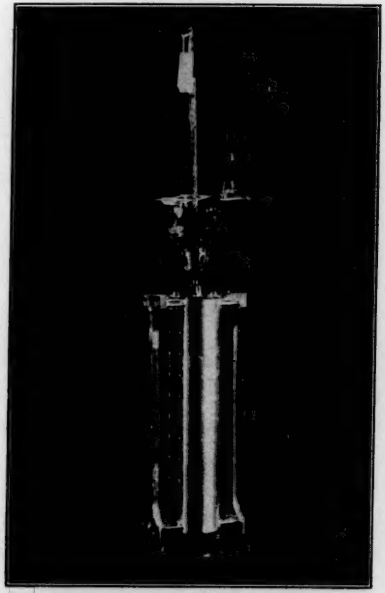

FIGURE 3.—MULTIPLE COUNTER USED WITH X-RAY EXPOSURE METER. CATHODE BLOCK IS MADE OF DURALUMINUM. CYLINDERS ARE LINED WITH 100 MESH BRASS GAUZE. WIRES ARE TUNGSTEN.

makes it possible to determine the correct exposure independently of all these variables. The sensitive element employed in this exposure meter is a G-M counter. For gamma radiography the slide rule is a good guide when the specimen thickness is accurately known and the geometry of the radiographic arrangement is simple. However, when the specimen is a casting of complicated shape, the choice of exposure time is somewhat of a hit or miss procedure. Here too, then, an exposure meter employed to indicate intensity at the film position would eliminate all uncertainty in exposure time and assure optimum density on every film.

The arrangement employed for using a G-M counter exposure meter with the 220 Kv. General Electric X-ray outfit at the Naval Research Laboratory is shown in Figure 2. The counter is mounted in a lead jug to guard against scattered radiation, and the jug is set on a movable chassis. A fixed indicator rod inserted in the base of the chassis and extending over the surface of the table permits easy location of the counter aperture with respect to the surface of specimens in position for radiographing. The counting circuits may be seen under the table and the measured intensities are indicated directly on a microammeter mounted on the control panel in the adjoining room. The circuit employed is a type of frequency meter which indicates counts per second in terms of current on the output meter. The type of G-M counter employed in the exposure meter is shown in Figure 3. Its operation is described in the appendix.

To calibrate the X-ray exposure meter, readings of the intensity indicator were recorded for voltages from 100 Kv. to 225 Kv. in steps of 25 Kv. for the range of steel thicknesses commonly radiographed at these voltages. The results of these measurements are plotted in Figure 4. Having obtained these relationships it was possible by reference to standard X-ray technique charts for steel (an example is Figure 5) to calibrate the meter readings in terms of the exposure necessary to produce a desired blackening of the film at a given kilovoltage. The calibration curve obtained for 0.8 density is shown in Figure 6. Although the calibration was carried through using steel test plates and technique charts, it applies equally well to other materials, as has been proven by tests on specimens of lead and brass.

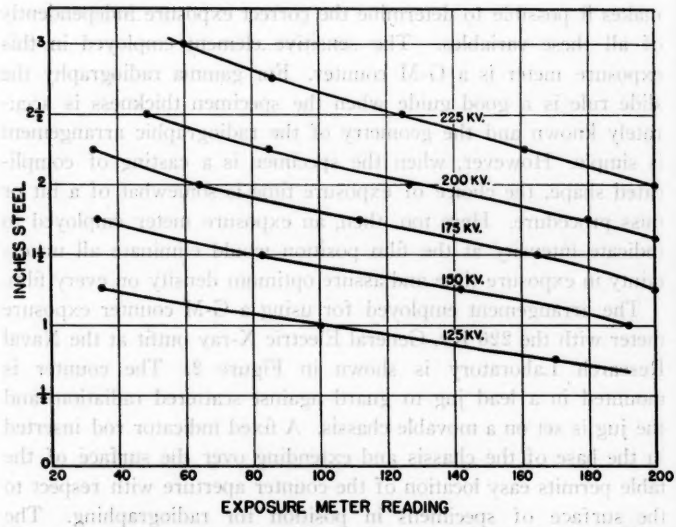

FIGURE 4.—THICKNESS OF STEEL PLATE PLOTTED AGAINST EXPOSURE METER READING AT VARIOUS KILOVOLTAGES.

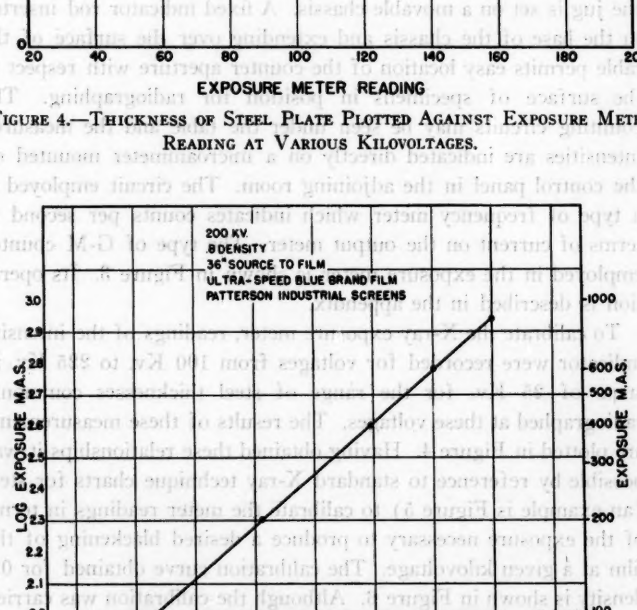

FIGURE 5.—TYPICAL TECHNIQUE CHART FOR STEEL.

At 100 Kv., the calibration of the meter readings against exposure time for a given density is quite different from that at 150 Kv. At higher voltages, the differences become very slight, and the calibration at 150 Kv. applies almost as well at 220 Kv. It is to be expected that at higher voltages the calibration will vary less for a given change of voltage than at lower voltages. As shown in Figure 7 the last critical absorption limit of the photographic emulsion occurs at 0.49A. With increasing kilovoltage, both the blackening of the photographic film and the current in an ionization chamber (correspondingly the Geiger Counter output) show a decreasing variation with kilovoltage.

With the decreased sensitivity of the film and the substitution of lead intensifying screens for fast chemical screens in gamma radiography, the efficiency of the counter method relative to the photographic technique of registering intensity becomes many times as great as in the case of the X-ray meter described above. For a gamma ray exposure meter, a small counter of the simple type shown in Figure 8 is adequate. In practice, the radium is mounted in position for radiographing, and the counter is brought up to the film position. The scale of the output meter may be calibrated for time of exposure.

The advantages to be gained by use of these exposure meters may be summed up as follows:

(1) While exposure meter readings are proportional to intensity, film blackening is proportional to the logarithm of intensity. The exposure meter, therefore, guarantees good density with considerable latitude in its reading. With the X-ray meter, any reading within almost full scale limits is enough to assure at least a fair result.

(2) In the neighborhood of 200 Kv. a change of only ten kilovolts requires a change of 150 per cent in exposure time to maintain a given film density. The exposure meter reads correctly almost independently of voltage above 150 Kv., but technique charts may be relied on only when the voltage is accurately known.

(3) The exposure meter, once calibrated for one metal or alloy will read correctly for all others.

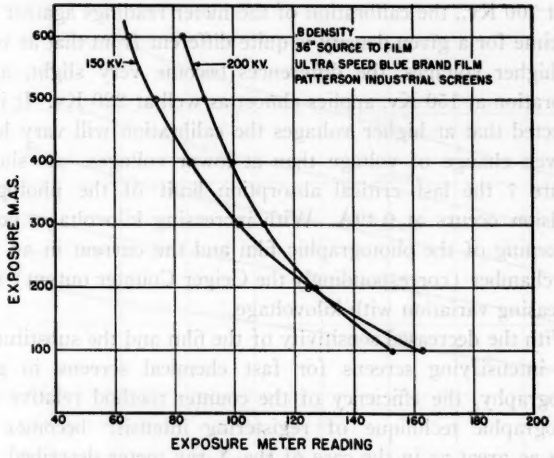

FIGURE 6.—X-RAY EXPOSURE METER CALIBRATION CURVE.

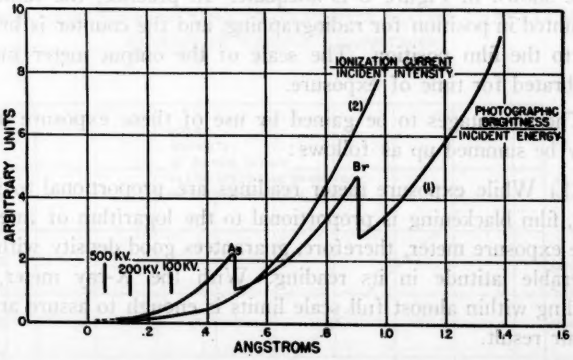

FIGURE 7.—WAVELENGTH DEPENDENCE OF FILM BLACKENING AND IONIZATION CHAMBER RESPONSE.

(4) Since the meter is read with the counter always at the film position, proper exposure will be indicated for any geometry of the radiographic set-up.

(5) When radiographing castings of variable thickness, the meters make it possible to determine the intensity of radiation

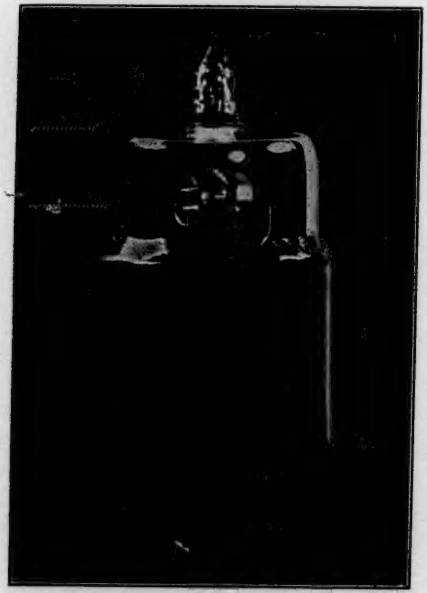

FIGURE 8.—COUNTER FOR GAMMA RAY EXPOSURE METER.

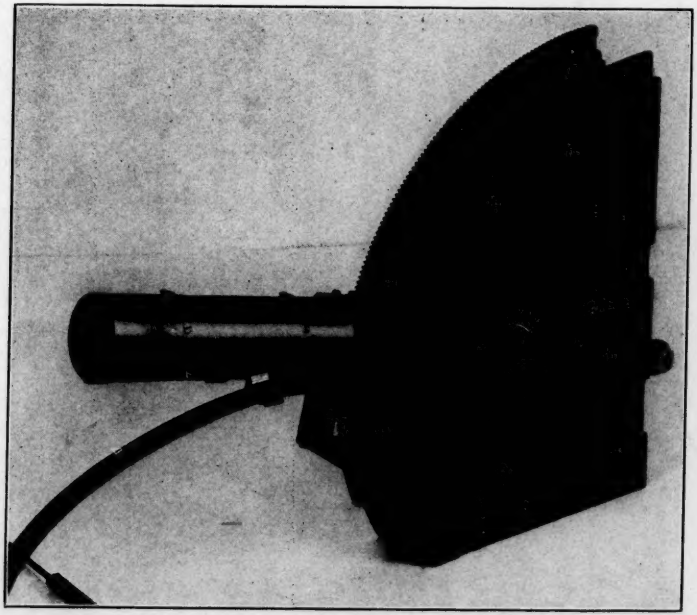

FIGURE 16.—MODIFIED DIFFRACTION CASSETTE FOR USE WITH G-M COUNTER.

transmitted through any portion of the specimen and to select a suitable compromise exposure. The loss of film and time involved in this type of radiography has always been an important consideration.

(6) High voltage X-ray equipment is rapidly coming into widespread use. Only very meager technique chart data are available for the many new high voltage radiographic outfits now being installed in plants engaged in war production. The use of an exposure meter would make it unnecessary to determine complete technique charts.

(7) The use of a gamma ray exposure meter opens up possibilities for short-lived sources such as radon and radio-yttrium, which at present are too difficult to work with because of the lack of knowledge of the extent to which the source has decayed.

The investment in radium is a major consideration in gamma radiography today, and considerable savings may be accomplished by eliminating time lost because of uncertainty of technique. The same applies to X-ray radiography, where the waste in film and time may be considerable. The efficiency of the X-ray exposure meter has been proven in daily use at the Naval Research Laboratory. In a recent problem, it was required to produce a set of radiographic standards in which all films were to be of the same density as closely as possible. Out of fifty exposures based on exposure meter indications, not a single film deviated by more than 3 per cent from the standard of 0.8 density, although the conditions of exposure varied sufficiently to require exposure times covering a range of more than three to one between extreme cases.

Dosage Measurement.

With the large number of high voltage X-ray outfits coming into industrial use at the present time, the problem of protecting the operators from injury, due to exposure to radiation leaks and scattered radiation, has become increasingly important. A means of rapid measurement of dosage in the neighborhood of X-ray equipment is essential. The tolerance dose for a normal working day is accumulated at a rate of about 10^{-5} roentgens per second. For exposure over periods of many days this rate must be reduced

to 10^{-6} roentgens per second. To cover a radiation laboratory with ionization chamber measurements is almost out of the question since it may require of the order of minutes to measure 10^{-5} roentgens per second. Furthermore, small radiation leaks most often will be missed. With a counter, 10^{-6} roentgens per second is easily measured in one second and accordingly, a laboratory may be completely covered in a reasonable time.

A. Trost[3] has studied the ratio of the response of a G-M counter to that of an ionization chamber filled with air. Dosage units are based on ionization effects in air and it is desirable to have a counter response that parallels that of the ionization chamber, with change in quality of radiation. The ordinary counter, enclosed in a glass envelope may be used in the region from 60 to 120 Kv. By covering the counter aperture with a millimeter sheet of tin and a one millimeter sheet of brass, good proportionality between counter and ionization chamber is obtained from 120 Kv. to 300 Kv.

Inspection with Counters.

The measurement of effective wall thickness in regularly shaped bodies by absorption of X-rays or gamma rays, offers fewest difficulties for a scanning method of inspection. Many attempts have been made to carry out rapid measurement of the thickness of metal sheet with ionization chambers, but although excellent sensitivity was achieved, the speed of measurement was too low to make the methods practical. The comparatively low current output of the ionization chamber required high amplification which could not be obtained without sluggish response. The usual method was to maintain the source of X-radiation and the ionization chamber fixed with respect to each other, and to move the metal sheet between them. By increasing the volume of the chamber, the speed of measurement could be stepped up, but this was accomplished at a loss of individual defect resolution. All the methods of increasing the sensitivity of the ionization chamber, including the use of dense gases at very high pressures, still left the instrument lacking in speed. Where the ionization chambers have failed however, Geiger-Muller counters are proving very successful.

The G-M counter has been adapted to many types of wall thickness measurements. When radium is employed as the source of gamma rays, it is fairly simple to estimate the gain in speed to be expected over photographic methods. Since 7×10^{10} quanta per second are emitted by one grain of radium, it may be seen from exposure times in gamma radiography that about 10^9 quanta per square centimeter of film surface are necessary to produce a density of 1.5. Generally, the limiting difference in film blackening that may be detected is about 2 per cent. Since blackening is proportional to the logarithm of intensity, the minimum detectable difference in intensity by the photographic method is greater yet. With a G-M counter, only 1100 counts are required to measure an intensity with a probable error of 2 per cent. The simplest type of tube counter (Figure 1) has a quantum efficiency of about one per cent, i.e., only one quantum is absorbed for every hundred that strike the counter. Such a counter would require only 110,000 incident quanta to yield the 1100 counts necessary for a 2 per cent probable error. With a counter aperture of one square centimeter, computation shows that the counter could be 100,000 times as efficient as film for a simple intensity measurement. Actually, it is possible to construct larger gamma ray counters with quantum efficiencies approaching 40 per cent and X-ray counters for wavelengths above 0.7 angstroms with close to 100 per cent efficiencies.

Now let it be assumed that a steel plate, three inches thick, is to be inspected with 100 milligrams of radium. With photographic film, the optimum source to film distance for best defect registration is 16 inches. With a 100 milligram source it is then possible to detect at best, a defect about 3 per cent of plate thickness deep by 3 per cent wide. For defects with greater width 2 per cent depth sensitivity is sometimes obtained. The exposure time with the fastest film now available would be about three hours.

If, instead of radiographing the plate, a G-M counter is used to scan it, there is no need for maintaining a source to counter distance greater than the thickness of steel being examined. Allowing for the size of the capsule in which the radium is held and the volume of the counter, the distance between center of source and center of counter may be taken as roughly five inches, with both source and counter as close to the plate as is practical.

There are approximately 7×10^9 quanta per second radiated over the entire solid angle from 100 milligrams of radium, and the linear absorption coefficient of steel may be taken as 0.35. Using these figures, one may quickly calculate that 2.5×10^5 quanta per second per square centimeter are incident on the counter. If counts were recorded for only 0.3 second, 720 would be obtained and the intensity would then be given with a probable error of 2.5 per cent.

When two measurements are each in doubt by approximately equal probable errors, their difference is generally in error by an amount somewhat greater than the uncertainty in an individual measurement. The factor obtained from probability theory is the square root of two. With a sensitive counter (about 1 count for ten incident quanta) and 0.3 seconds per measurement, the difference between any two measurements of transmitted intensity will have a probable error of 1.2 per cent. Now because of the exponential nature of the absorption of gamma rays, a thickness change of only 2.5 per cent in 3 inch steel plate will alter the transmitted intensity by 5.3 per cent. It is therefore safe to conclude that simple detection of a 2.5 per cent thickness difference is practically certain when measurements of 3 inch plate are each made in 0.3 second with a 100 milligram source.

Suppose the effective thickness of the test piece must be known over its entire surface. With photographic registration, the optimum source to film distance quoted above applies only to a film area less than 5 inches $\times$ 7 inches; the photographic method, therefore, will indicate thickness variations over an area of about 150 square centimeters, with a sensitivity of 2.5 per cent, and will require an exposure of three hours. When scanning with the counter, the source and counter are maintained fixed with respect to each other and the test plate is moved between them. If the area of the plate is covered one square centimeter at a time, it may be scanned in about 45 seconds with an accuracy sufficient to pick up an effective thickness change of 2.5 per cent.

To sum up then, in the above comparison a counter with an efficiency of 10 per cent will give a more accurate average thickness measurement than film in about 1/240 of the time required for a photographic exposure. The photographic method, how-

ever, will show up individual 2.5 per cent defects having a diameter somewhat less than one quarter inch, whereas the counter as used above, will rapidly lose efficiency if the aperture diameter is cut down to increase its resolution of individual defects.

The counter scanning method gains considerably in speed over photographic technique when thicker sections are inspected. For a six inch steel plate at 18 inches source to film distance, a forty hour exposure is necessary with 100 milligrams of radium. The photographic method cannot do much better than 4 per cent defect sensitivity in this case. If a counter method of scanning like that described above, is employed, similar calculations show that the scanning can be completed 1600 times as quickly as the radiograph. If a more practical method of scanning is used, for example, a continuous motion at one half the above rate and with overlapping traces, the time would be increased by a factor of four. This still leaves a large advantage of 400 times in speed. Furthermore, the counter aperture of one square centimeter is not much larger than the minimum cross-section of the 4 per cent defect detectable photographically.

From the above comparisons it is obvious that for measurements of effective thickness, counters may be substituted for film with great gain in efficiency. The major disadvantage of the counter used in conjunction with radium is the limiting size of the aperture that defines the measured beam of radiation. It is impractical to try to reduce this aperture below one square centimeter. On film the corresponding limit is of the order of 1/25 square millimeter. For the detection of fine tears, cracks, individual small blow-holes and small shrinkage cavities with gamma radiation, the use of film is to be preferred. On the other hand, for detection of wall thickness changes, corrosion areas, large cavities and general porosity, the counter is a superior device. When employed in inspection for the latter defects the counter has the advantage of greater sensitivity, higher speed and quantitative accuracy.

All of the above considerations apply equally well to X-radiation. In general, the intensities available are much higher than in gamma ray inspection, necessitating faster counting circuits and

permitting higher speeds of scanning. An important difference is that the counter aperture may be cut down as far as desired with relatively small amounts of lead shielding.

Counter measurements of thickness of very thin sheet are relatively accurate when soft X-radiation is used. The high absorption of such radiation makes the amount of transmitted intensity very sensitive to thickness. Foils of lead, tin, brass, copper, and steel of the order of 0.005 inch thickness have been measured with a precision of $\pm$ 1.0 per cent in one tenth second.[3] Over the range from 0.005 to 1.0 inch of steel, thickness has been measured in one tenth second with an accuracy of 0.5 per cent.

In many problems of wall thickness measurement the use of common photographic technique is out of the question for purely mechanical reasons. In some cases, such as the examination of large pipes, gas cylinders and pressure vessels, the examination by counter scanning methods is easily accomplished. A typical ar-

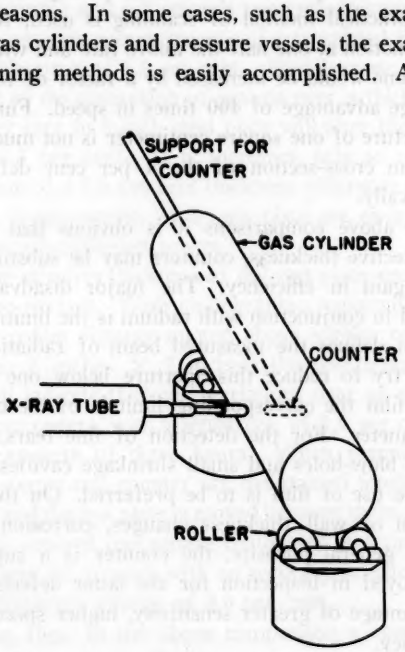

FIGURE 9.—ARRANGEMENT FOR EXAMINING A CYLINDER. ROLLERS ARE SET OBLIQUELY TO PRODUCE A SLOW FORWARD MOTION AS THE CYLINDER IS ROTATED.

rangement for inspection of a gas cylinder is sketched in Figure 9. The counter is mounted on a long extension arm running the depth of the cylinder. The X-ray tube is fixed in position with its target radial with the counter and as close to the outside of the cylinder wall as possible. Hollow anode tubes serve the purpose particularly well. The cylinder itself is set on a roller track to permit rotation and in addition the rollers are set obliquely so as to produce a slow forward motion as the cylinder is rotated. The intensity meter is observed during rotation of the cylinder and indicates deviations from the normal thickness.

In cases where the specimen is fixed in position, either the X-ray tube or radium capsule is maintained fixed inside the pipe or cylinder and the scanning is accomplished by moving the counters on the outside. Obviously the geometry must be such that the change in distance from counter to source during motion of the counter is not great enough to mask the effect of a small change in wall thickness. Steel thicknesses of the order of 2 inches may be checked to within 1/2 per cent with scanning speeds as high as 1/10 second per point when using counters with 3/4 inch apertures and X-ray tube voltages between 250 and 300 Kv. If radium is used, the capsule is as easily handled as the counter and they can be used interchangeably. The radium may be mounted on the end of a sufficiently long rod, used as a probe by the inspector.

The counter, normally, is better adapted to detecting general porosity than to picking out individual cavities. Cavities may be readily found, only when their cross-section is comparable to the counter aperture. Accordingly, the counter should be used for cavity detection only in heavier sections, where any holes under 3/16 or 1/8 inch in diameter may be neglected. A thickness sensitivity of 1 millimeter is ordinarily obtainable with radium in sections of the order of four inches or more in thickness. (This sensitivity of course is a function of the speed of measurement, strength of source, and counter aperture.) The minimum diameter cavity that may be detected is generally much greater than the minimum wall thickness, but, if a small bead of radium is mounted on the end of a probing rod (Figure 10), cavities as small as 1/8 inch in diameter, in 4 inch thick steel wall, may be

picked up by running the radium pellet over the outer surface while maintaining the counter fixed on the inner side. The solid angle subtended by the counter with the radium pellet as center determines the minimum size cavity that can be detected. In inspecting castings with changing cross-sections such as flanges, by this method, the probing may be concentrated in the region where the cavities are most likely to occur.

Many arrangements may be resorted to in inspection to suit the needs of particular problems. To eliminate the effects of variations in X-ray intensity, or to facilitate the detection of individual cavities in sections of varying thickness, two counters may be operated in a null arrangement, analagous to the compensation arrangements of twin ionization chambers. The counters may be mounted side by side in the same envelope and thus occupy only slightly more space than a single counter (Figure 11). Such counter combinations have been employed in determining the extent of center-line pipes in ingots. The ingot rests on a table equipped for two way motion. The radium capsule and the differ-

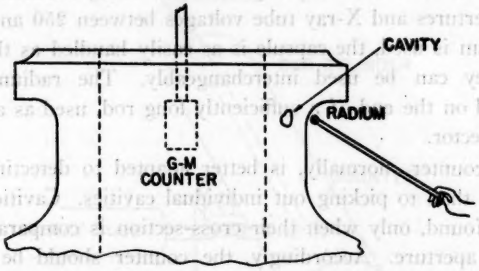

FIGURE 10.—EXAMINATION OF A FLANGE IN A VALVE CASTING.

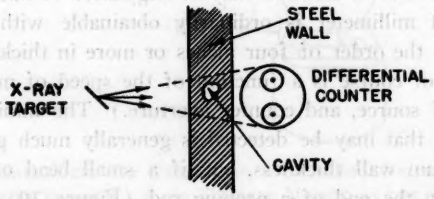

FIGURE 11.—INSPECTION WITH A DIFFERENTIAL COUNTER ARRANGEMENT.

ential counter are fixed in position while the ingot is moved along its axis in steps and scanned with a continuous motion at right angles to the direction of the pipe.

In cases where it is impossible to work with the counter and radiation source on opposite sides of the specimen wall, it is often possible to utilize scattered radiation as a measure of effective wall

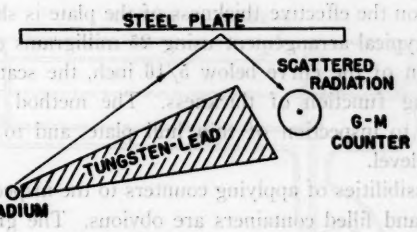

FIGURE 12.—MEASUREMENT OF PLATE THICKNESS WITH SCATTERED RADIATION.

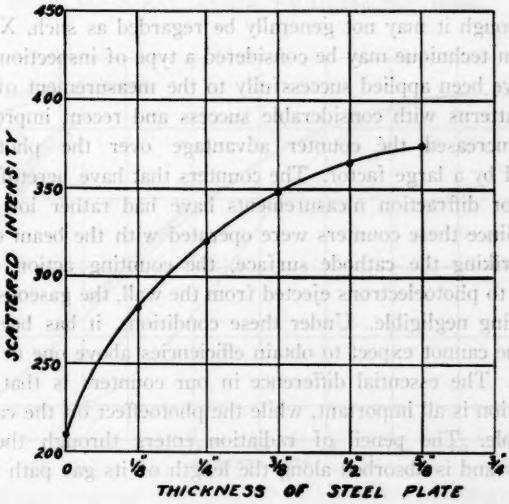

FIGURE 13.—VARIATION OF SCATTERED INTENSITY WITH PLATE THICKNESS.

thickness.* In Figure 12 is shown an arrangement employed for measuring effective thickness of steel plate up to 1/2 inch thick. The radium pellet and the counter are separated by 10 centimeters of shielding consisting of tungsten buttons with lead filler. This cuts down the radiation directly received by the counter to considerably less than the amount scattered to it from the plate being examined. The dependence of the intensity of scattered radiation on the effective thickness of the plate is shown in Figure 13 for a typical arrangement using 25 milligrams of radium. On the portion of the curve below 5/16 inch, the scattered intensity is a strong function of thickness. The method is particularly applicable to inspection of thin hull plate, and to measurements of liquid level.

The possibilities of applying counters to the inspection of coated materials and filled containers are obvious. The great sensitivity of soft X-ray absorption to the atomic number of the absorbing material makes possible very rapid inspection.

X-Ray Diffraction.

Although it may not generally be regarded as such, X-ray diffraction technique may be considered a type of inspection. Counters have been applied successfully to the measurement of diffraction patterns with considerable success and recent improvements have increased the counter advantage over the photographic method by a large factor. The counters that have heretofore been used for diffraction measurements have had rather low efficiencies. Since these counters were operated with the beam of radiation striking the cathode surface, the counting action was due mainly to photoelectrons ejected from the wall, the gaseous absorption being negligible. Under these conditions, it has been shown that one cannot expect to obtain efficiencies above one or two per cent[4]. The essential difference in our counters is that gaseous absorption is all important, while the photoeffect on the cathode is negligible. The pencil of radiation enters through the bubble window and is absorbed along the length of its gas path (Figure

* The authors are indebted to Dr. D. G. C. Hare of the Texas Company for information obtained from him relative to methods of inspection with scattered radiation and the design of sensitive counters.

14). The gaseous volume is made up of a rare gas at atmospheric pressure together with a small amount of alcohol vapor. From Figure 15 it is evident that, for the characteristic X-radiations of molybdenum, copper, cobalt, iron and chromium targets, the beam of radiation may be almost entirely absorbed in a ten centimeter length of path, if proper gas and pressure are selected.

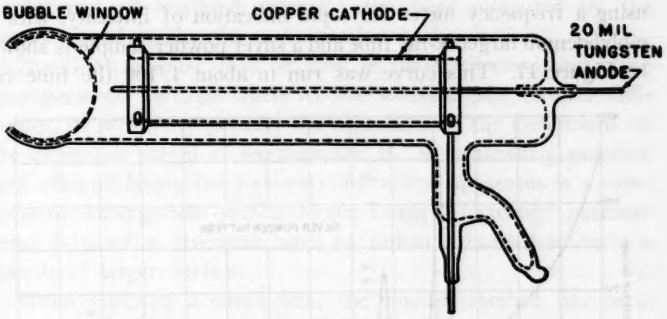

FIGURE 14.—X-RAY COUNTER FOR DIFFRACTION WORK.

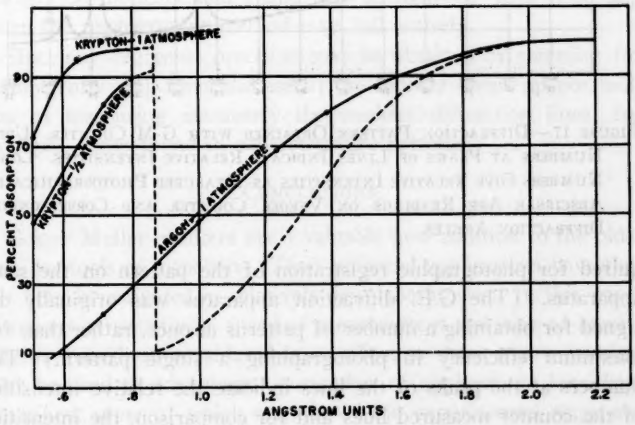

FIGURE 15.—ABSORPTION OF X-RADIATION BY ARGON AND KRYPTON IN A TEN CENTIMETER COUNTER.

Our first attempts to measure diffraction intensities with counters were carried out with a modified G.E. cassette (Figure 16). A counter was mounted in the jacket at the end of the radius arm, and traversed the 90 degrees arc normally covered by film. Positions of the slit in front of the counter window were read on the Veeder counter to a tenth of a turn, corresponding to one fiftieth of a degree of arc. Part of one of the first curves obtained using a frequency meter for rapid indication of intensity, with a molybdenum target X-ray tube and a silver powder sample is shown in Figure 17. This curve was run in about 1/100 the time re-

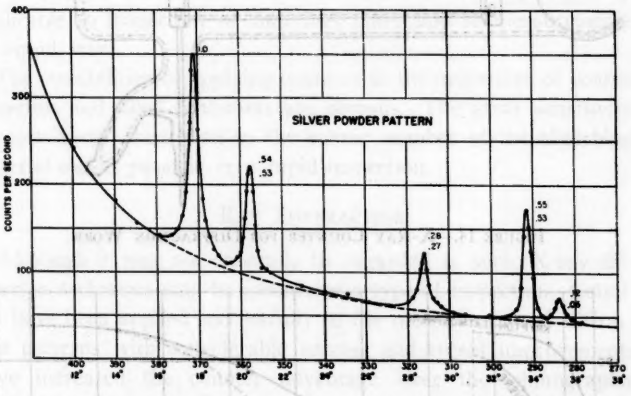

FIGURE 17.—DIFFRACTION PATTERN OBTAINED WITH G-M COUNTER. UPPER NUMBERS AT PEAKS OF LINES INDICATE RELATIVE INTENSITIES. LOWER NUMBERS GIVE RELATIVE INTENSITIES AS MEASURED PHOTOGRAPHICALLY. ABSCISSAE ARE READINGS ON VEEDER COUNTER AND CORRESPONDING DIFFRACTION ANGLES.

quired for photographic registration of the pattern on the same apparatus. (The G.E. diffraction apparatus was originally designed for obtaining a number of patterns at once, rather than for maximum efficiency in photographing a single pattern.) The numbers at the peaks of the lines indicate the relative intensities of the counter measured lines and for comparison, the intensities determined by photographic comparison methods by Hanawalt, Rinn, and Frevel.[5] The counter obviously combines speed with quantitative accuracy of intensity measurement.

A photograph taken of the silver pattern on the same apparatus was micro-photometered. Comparison of the micro-photometer trace with the G–M. counter curve showed strikingly the extent to which scattered radiation contributes to the background of photographic patterns and how difficult it is to show a large range of intensities photographically on a single film. In contrast to the diffuse peaks of the photographed lines superimposed on a large background of scattered intensity, the lines measured by the counter stand up sharply on a very low background.

The G–M. counter may be used in back reflection and other arrangements. In cases where its size would appear to offer difficulties, its sensitivity permits the expansion of the dimensions of the diffraction set-up to accommodate it. A particularly practical and efficient design for a counter diffraction apparatus is a spectrometer arrangement similar to the Bragg "focusing" arrangement in which a divergent beam of radiation is used to cover a sample of larger surface.

When studying a single line, the counter method has great superiority over film, especially if the line is changing in intensity and width during the time of measurement. With the counter, the changes in intensity and shape can be followed with little lag, when the photographic method may fail entirely.

Since any degree of precision may be obtained by counting for a sufficiently long time, the use of the counter opens up possibilities of measuring accurately the weakest diffraction lines, for example, those found in superstructure patterns.

Conclusions.

Geiger-Muller counters are a valuable new addition to the older familiar tools of inspection. Their potential applications have thus far been investigated in relatively few laboratories. In this paper questions of sensitivity, speed of measurement and ease of manipulation, have been considered in an effort to show where counters may be used to advantage. A number of applications have been described, some of which are out of the experimental stage and should receive widespread use. Others are still in an early state of development and leave considerable room for further improvement.

APPENDIX.

I. The Counter Mechanism.

In general, counters are classified as fast or slow. Fast counters differ in construction from slow counters only in the addition of a small amount of vapor such as alcohol, xylene, or petroleum ether, to the body of gas in the counter (generally argon). The slow counter is impractical for the applications that have been described. The fast counter[6], which dates from about 1935, has made possible rapid measurement with high sensitivity and since it is the type employed in all the applications, we shall confine the following discussion to fast counters.

Assuming a constant initial amount of ionization produced by absorption of radiation in the tube, the charge collected by the electrodes will, of course, vary with the applied potential difference. Whether the tube being described here behaves as an ionization chamber, a proportional counter, or a G-M counter depends entirely on the potential difference between the electrodes. At the lowest voltages, the charge collected is limited by recombination, but with increasing voltage saturation is soon reached and practically all the initial ions are collected. At this stage, the tube is acting as an ionization chamber and the amplification factor is unity. With further rise in voltage, gas amplification sets in. The region that follows is one of proportional amplification. The field strength, which increases inversely as the distance from the center of the wire, has now been raised to where ionization by electron impact is possible close to the wire. As the original electrons are accelerated toward the wire, they collide with atoms and produce electron and positive ion pairs. These newly formed electrons are in turn accelerated and produce still further ionization. The process is cumulative and is known as a "Townsend avalanche." Proportional amplification holds up to a factor of about 10^5. Still further increase in voltage raises the amplification factor, but the proportionality disappears. This is the condition at the foot of the G-M counting region. Irrespective of the initial amount of charge, the charge finally collected by the electrodes now becomes a constant at any given voltage. The amplification for a single original electron, (Figure 18) approaches a magnitude of 10^{10}. Above

the G-M region continuous discharge sets in. The action in the Geiger-Muller region is distinguished from the proportional amplification mechanism in that sufficient kinetic energy has become available for the excitation of short wavelength radiation by electron atom impacts. These light quanta then produce photoelectrons that ignite repeated avalanches. The discharge is even-

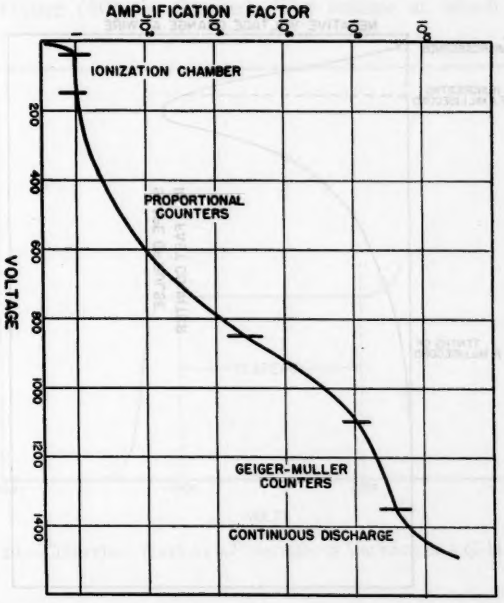

FIGURE 18.—AMPLIFICATION FACTOR IN A TUBE COUNTER AS A FUNCTION OF APPLIED VOLTAGE.

tually cut off by the development of a positive ion space charge sheath in the neighborhood of the wire. This occurs when the ion sheath is large enough to lower the accelerating field inside it below the minimum required for impact ionization.

If a Geiger-Muller counter is operated in the fundamental circuit of Figure (1) the potential pulses on the wire as observed on an oscilloscope screen have the shape shown in Figure (19).

The triggering of the avalanche process produces a rush of billions of electrons to the wire, before the discharge is quenched by the space charge action. These electrons are collected in less than 1/10 microsecond, but during that time, the heavy positive ions drift only a very slight distance from the wire. The total charge displacement in the first microsecond is therefore very small and correspondingly the potential drop at the wire is very

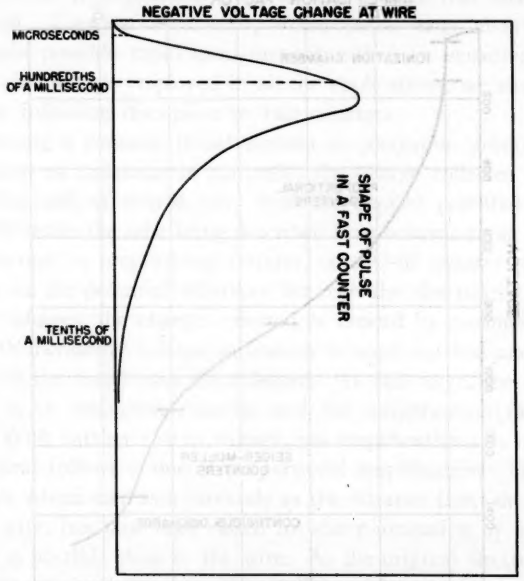
NEGATIVE VOLTAGE CHANGE AT WIRE
MICROSECONDS
HUNDREDTHS OF A MILLISECOND
TENTHS OF A MILLISECOND
SHAPE OF PULSE IN A FAST COUNTER

FIGURE 19.—TYPICAL PULSE SHAPE IN A FAST COUNTER.

slight. During the next ten microseconds, there is a steady potential drop at the wire, while the positive ion sheath drifts toward the cathode. At the same time, the negative charge leaks off the wire rapidly because of the small leak resistance used with a fast counter. The remainder of the pulse indicates the recovery of the wire to its original working voltage as the positive ions are completely cleared out. The entire breakdown-recovery process spans a period of a few tenths millisecond.

The production of a voltage pulse at the counter wire, in the manner just described, may be repeated every time a quantum of radiation is absorbed. It is apparent then, that by electrically counting the number of pulses per unit time one can obtain a measure of the intensity of radiation entering the counter. If the counting rate due to a constant intensity of radiation is determined as a function of voltage applied to the counter, the characteristic curve, Figure (20), is obtained. The voltage at which the gas

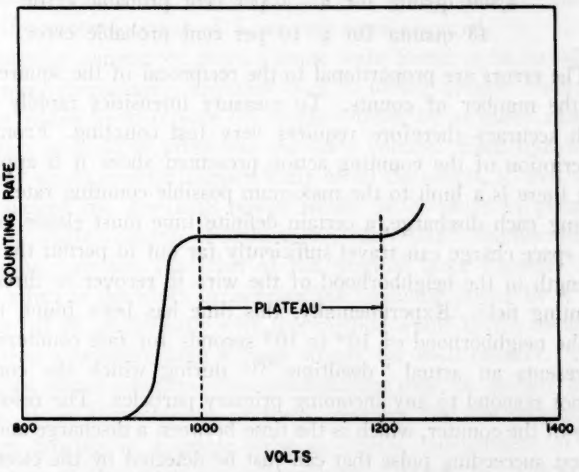

FIGURE 20.—COUNTING RATE AS A FUNCTION OF VOLTAGE IN A G-M COUNTER.

amplification becomes independent of primary ionization in the counter may be called the G.M. threshold, and the term overvoltage is applied to the difference between the operating and threshold voltages. At the threshold, the number of counts per unit time reaches a value that increases only slightly over the next one hundred to two hundred volts. The region over which the counting rate is independent of overvoltage is known as the "plateau", and its length and flatness are a measure of the quality of the G–M. counter.

II. Resolving Time.

The counter pulses resulting from irradiation with X or gamma rays occur in a random distribution, and the laws of pobability that apply to all random errors of measurement determine the precision of any intensity measurement as a function of the number of quanta counted. The number of quanta that must be counted to measure an intensity with various probable errors are:

430,000 quanta for a 0.1 per cent probable error.
4,300 quanta for a 1 per cent probable error.
43 quanta for a 10 per cent probable error.

The errors are proportional to the reciprocal of the square root of the number of counts. To measure intensities rapidly with high accuracy therefore requires very fast counting. From the description of the counting action presented above it is apparent that there is a limit to the maximum possible counting rate. Following each discharge, a certain definite time must elapse before the space charge can travel sufficiently far out to permit the field strength in the neighborhood of the wire to recover to threshold counting field. Experimentally, this time has been found to be in the neighborhood of 10^{-4} to 10^{-5} seconds for fast counters and represents an actual "deadtime"[7] during which the counter cannot respond to any incoming primary particles. The resolving time of the counter, which is the time between a discharge and the closest succeeding pulse that can just be detected by the electrical system coupled to the counter, can be reduced by decreasing the leak resistance and increasing the overvoltage, but can never be less than the deadtime. Assuming a resolving time of 10^{-4} seconds, a maximum counting rate of 10,000 uniformly spaced pulses per second would be possible. However, if an intensity must be measured in one second with a mean error of 1 per cent, it does not suffice to be able to count 10,000 regular pulses per second. There are large fluctuations in the intervals between pulses of a random distribution such as is obtained from a radium source of gamma rays. Furthermore, the shortest time intervals are the most probable, so that even at counting rates far below the resolving power of the counter, many pulses come too close together to be

resolved. For example, the counter we are considering would miss about ten per cent of the quanta absorbed, at a counting rate of 1000 per second.

In some applications the intensities do not exceed 1000 counts per second, and the simple tube counter suffices. In many instances, however, the intensities available are very high so that it becomes desirable to increase the resolution of the counter many orders of magnitude, to permit measurements at maximum speeds. For example, if a surface were to be scanned at a rate of 1/10 second per point, then 450,000 counts per second would be necessary if a probable error of 1 per cent were required.

Assume a counter of given volume were found to be too slow. The most immediately apparent way to obtain greater resolving power would be to replace the single counter by as many smaller counters as could be fitted into the same volume. Each individual counter would operate independently of all the others, so that with N counters, the resolving power would be N times as great as with a single counter. Furthermore, each small counter has a resolving time less than that of the original large counter. The total effect is therefore to increase the resolving power by a few factors of N. A difficulty with this method would be the necessity of using a separate high voltage supply for each counter. With the fast vapor counters, this disadvantage may be quickly overcome. It is characteristic of these counters that the amount of charge flowing in a single pulse is almost independent of the circuit constants and varies only with the overvoltage. The potential pulse on the wire during a discharge, may therefore vary in magnitude from zero to more than the full overvoltage, depending on the wire capacity. In most cases, the capacity is large enough so that the counter wire drops only a fraction of the overvoltage. If now, instead of operating N counters independently, they are simply connected in parallel, the discharge in any individual counter will produce only a small pulse on the wire system and so have very little effect on the operating conditions of the other counters. The deadtime of each individual counter will remain unaffected. In spite of the parallel arrangement, the counters continue to act practically independently of each other. By substi-

tuting a bundle of seven small diameter counters for a single large counter of equal volume (Figure (21)), the resolving power was found to increase by a factor of 15. For some problems, multiple counters have been constructed with as many as 25 individual counters in parallel (Figures (22, 23)). The limitations on the possible gain in resolution by this technique are mainly mechanical difficulties of construction and the reduction of pulse size to where detection with fast pulse amplifiers becomes difficult, in direct counting methods. (The latter difficulty does not occur in circuits which measure the average current flow through the series resistor, rather than the number of pulses.)

When the available intensities are sufficiently strong to produce 100,000 or more quantum absorptions per second in the counter, it is no longer possible to use the G-M counter in the normal manner. However, with such great intensities, the extreme amplification of the G-M counter is no longer needed for high speed response. By working at voltages below the G-M counting threshold, counting rates up to a million per second may be measured with good linearity between counter current and intensity, while still retaining amplification factors of the order of 10^5.

III. Circuits.

The problem of obtaining high resolution in the counter is intimately connected with the problem of measuring counting rates. It is useless to strive for high resolution in the counter if the associated electrical circuit will not match that resolution. The various circuits adapted for use with counters fall into two classes, those in which individual pulses are amplified and counted and those in which only the average current flow in the counter leak resistance is measured. In the former case, the pulses may actually be " counted " or simply integrated in a tank circuit, with a meter to read the average current.

In direct counting, the amplified pulses can be totaled on an impulse counter if the counting rate is very low. The popular Cenco counter is capable of handling about seventy regular pulses per second. In random counting, however, only a very few counts per second can be handled without much loss. At higher

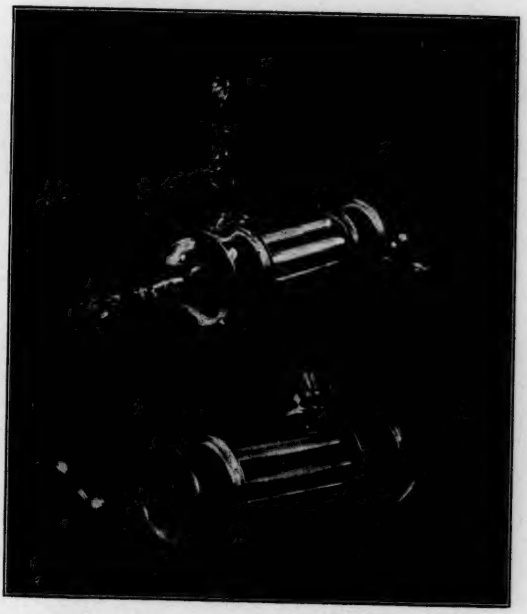

FIGURE 21.—MULTIPLE COUNTER MADE UP OF SEVEN SIMPLE COUNTERS IN PARALLEL.

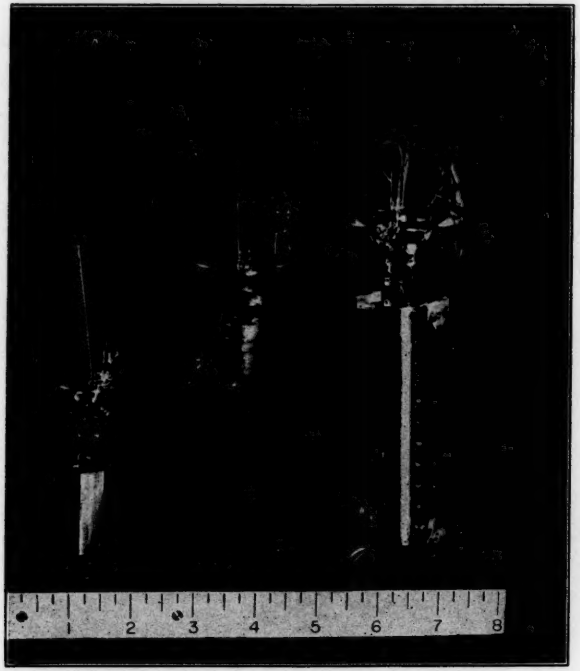

FIGURE 22.—MULTIPLE COUNTERS.

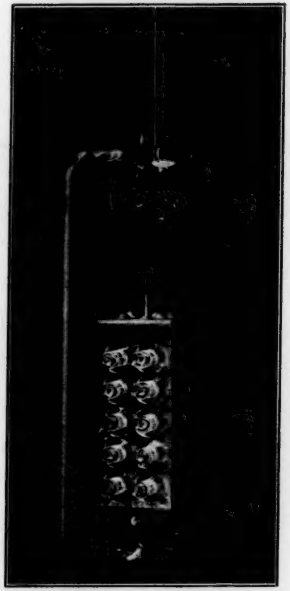

FIGURE 23.—MULTIPLE COUNTER. WIRES ARE CENTERED THROUGH MICA DISKS AND GLASS CAPILLARY TUBING. ALL CYLINDERS ARE BRASS MESH MOUNTED IN DURALUMINUM BLOCK. WIRES ARE 5 MIL TUNGSTEN. ALL COUNTERS SHOWN IN THIS PAPER HAVE BEEN CONSTRUCTED BY W. B. HALLIDAY AND F. C. STRICKER OF THE GLASS-BLOWING SHOP AT THE NAVAL RESEARCH LABORATORY.

rates, it is essential to scale down the number of pulses from the G-M counter by a fixed ratio, before feeding the mechanical counter. The fundamental unit of a scaling circuit[8] is a vacuum tube scale of two, (Figure 24), which is simply an electronic

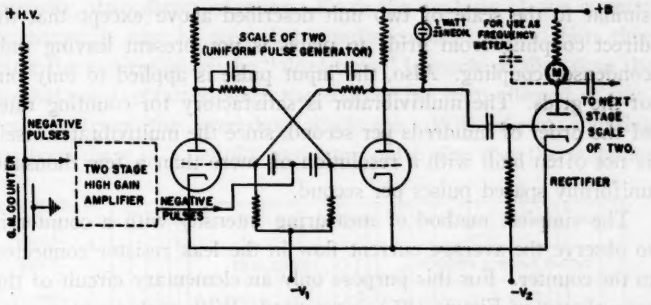

FIGURE 24.—SCALE OF TWO CIRCUIT AND FREQUENCY METER.

switch plus a rectifier. Every two negative pulses fed to this unit yield one output negative pulse from the rectifier stage. The important feature of this circuit is its extreme speed, giving a resolving time of 6×10^{-6} seconds and permitting counting rates of 5000 random counts per second with only 3 per cent loss. Seven such scales of two in series feed the mechanical counter only one pulse for every 128 input pulses. Accordingly, at a counting rate of 1280 per second, the impulse counter has to handle only ten per second.

A substitute for the scaling circuit-impulse counter method is the frequency meter circuit. The heart of the circuit is again the scale of two unit shown in Figure (24). It generates equal-sized output pulses for all input pulses, so that the average current flowing in the plate resistor of the rectifier is directly proportional to the number of pulses per unit time. This current is conveniently indicated by a microammeter in series with the plate resistor. The fluctuations due to the randomness of the pulses are averaged out by placing a condenser across the meter and plate resistor. This frequency meter method is most practical for fast counting rates, for by choosing a condenser that will give the

indicator a period of one second, it is possible to show continuously the average current of 5000 random counts per second with a probable fluctuation in reading of only 1 per cent.

A more commonly employed type of uniform pulse generator for a frequency meter circuit is the multivibrator. It is very similar to the scale of two unit described above except that the direct coupling from grids to plates is not present leaving only condenser coupling. Also, the input pulse is applied to only one of the grids. The multivibrator is satisfactory for counting rates of the order of hundreds per second, since the multivibrator itself is not often built with a resolution of more than a few thousand uniformly spaced pulses per second.

The simplest method of measuring intensity with a counter is to observe the average current flow in the leak resistor connected to the counter. For this purpose only an elementary circuit of the type shown in Figure (25) is required. With each counter pulse

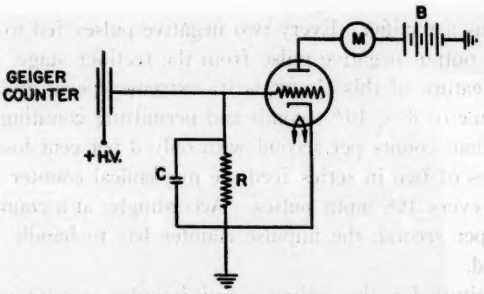

FIGURE 25.—SIMPLE INTENSITY METER CIRCUIT.

there is a flow of current in the resistor R. At high counting rates, the average potential drop across R due to the flow of current through the counter is sufficient to produce a current change of the order of milliamperes in the meter included in the plate circuit of the triode. The current sensitivity may be adjusted by varying the resistance R and the fluctuations due to the randomness of count production are smoothed out by the condenser C.

This method of current measurement to indicate intensity has the disadvantage that the counter voltage must be carefully stabi-

lized, since the current flow per pulse is approximately proportional to overvoltage. In direct counting, the change in counting rate for small changes in overvoltage is generally negligible in a good counter. The counter-current method, however, gives much better proportionality between incident intensity and measured intensity, than direct counting. From the analysis of the counter discharge, it may be seen that a pulse coming only a short time after the expiration of the " dead-time " is much smaller than the normal pulse, obtained when the counter has been allowed to fully recover from the preceding discharge. With direct counting methods there is a definite minimum pulse size that the amplifier

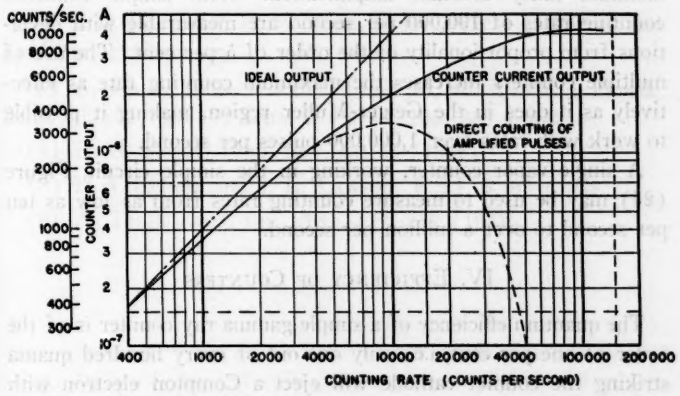

FIGURE 26.—VARIATION OF COUNTER-CURRENT OUTPUT, AND COUNTING RATE MEASURED WITH PULSE AMPLIFIER COUPLED TO COUNTER. BOTH CURVES ARE FOR THE SAME COUNTER. (AFTER TROST)

will respond to. When the counting rate is so high that many pulses smaller than this minimum begin to appear the indicated counting rate begins to deviate from linearity and eventually falls to zero with increasing counting rate. The counter-current indication is made of contributions from all size pulses and therefore will saturate, but never drop toward zero. The deviations from linearity by a counter-current method and by a direct counting method[9] are compared in Figure (26) where it is assumed that the amplifier cannot respond to pulses less than half the normal pulse size.

For very high counting rates, the counter current technique may be used with the counter operating in the region from 50 to 200 volts below its threshold for Geiger-Muller counting. As shown in Figure (18) the amplification factor in this range is still very high. The rate of decrease of amplification with decreasing voltage is a function of the gas filling in the counter and the wire size. With non-vapor counters the slope of the amplification curve is very sharp and the problem of stabilizing the voltage sufficiently to permit working on any part of the slope is much too difficult. With vapor counters the slope of the amplification curve may be reduced to where the stabilization is sufficient to maintain fairly constant amplification. With simple counters, counting rates of 100,000 per second are measurable with deviations from proportionality of the order of 5 per cent. The use of multiple counters increases the maximum counting rate as effectively as it does in the Geiger-Muller region, making it possible to work with rates over 1,000,000 pulses per second.

A single vapor counter, working in the simple circuit, Figure (25) may be used to measure counting rates from as low as ten per second to over a million per second.

IV. Efficiency of Counters.

The quantum efficiency of a simple gamma ray counter is of the order of one per cent, i.e., only one out of every hundred quanta striking the counter cathode will eject a Compton electron with sufficient energy to get out of the metal into the gaseous volume of the counter. By increasing the effective surface area of the cathode, for example by using a closely woven wire mesh, the efficiency may be increased by about a factor of two. The multiple counters already described were intended for increased efficiency as well as for greater resolving power. Since the probability of absorbing a gamma quantum in one cylinder is of the order of 2 per cent, the effect of allowing the beam to pass through a line of ten mesh cylinders is to bring the efficiency of the combination up to practically 20 per cent. The counters of Figures (22, 23) were intended for use with collimated beams. Tests made with multiple counters in which the wire leads were brought out indi-

vidually, showed that the increase in counting rate with increasing number of counters in parallel, was fairly closely proportional to the number of counters, in a ten cylinder combination.

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SUCCESSFUL SUBSTITUTION OF NON-CRITICAL METALS FOR CRITICAL METALS IN COMPRESSED AIR RADIATION.

By Lieutenant-Commander L. F. Wilson, U.S.N.R., (Ret'd).

For several years there has been available a grid-sectional type of radiation particularly suited to the cooling of compressed air to precipitate moisture. For purposes of variability to meet seasonal atmospheric temperature changes, these grid sections are mounted in pairs for parallel flow, with either automatic, or manual cutout valve as shown in Figure 2.

Originally these grid sections consisted of composite castings with a center of alloy iron upon which was cast the grid fin structure in aluminum. Despite the fact that this class of equipment, when for installation on steam, Diesel-electric, or electric locomotives, carried an A-3 priority rating, the necessity for strict allocation of aluminum to direct military uses necessitated substitutive metals. This has been successfully worked out.

The new grid section is integrally cast in alloy iron as shown in Figure 1. While it is an extremely difficult casting to make, involving a considerable percentage of foundry rejects, it has been found to be the equal, per lineal foot, of the original aluminum fin structure in radiation effectiveness. This, at first thought, seems inconsistent because of the higher co-efficient of heat conductivity of aluminum as compared with iron. The deciding factor in this class of radiation effectiveness, however, has been shown not to lie in actual metal conductivity, but in the speed with which the heat units are dispersed to the ambient atmosphere from the surface of the fins; and any strong movement of ambient air cannot be counted upon, in locomotive air-brake or similar service.

Comparative heat conductivity of the metals, therefore, appears to have almost nothing to do with the effectiveness of this radiation, provided only that the heat units are carried to the surface as fast

as they can be carried away, which by comparative tests has proven to be effected by the use of iron, under the conditions described.

With respect to the installation of this equipment, it must, of course, be securely and strongly supported, but the simplicity of

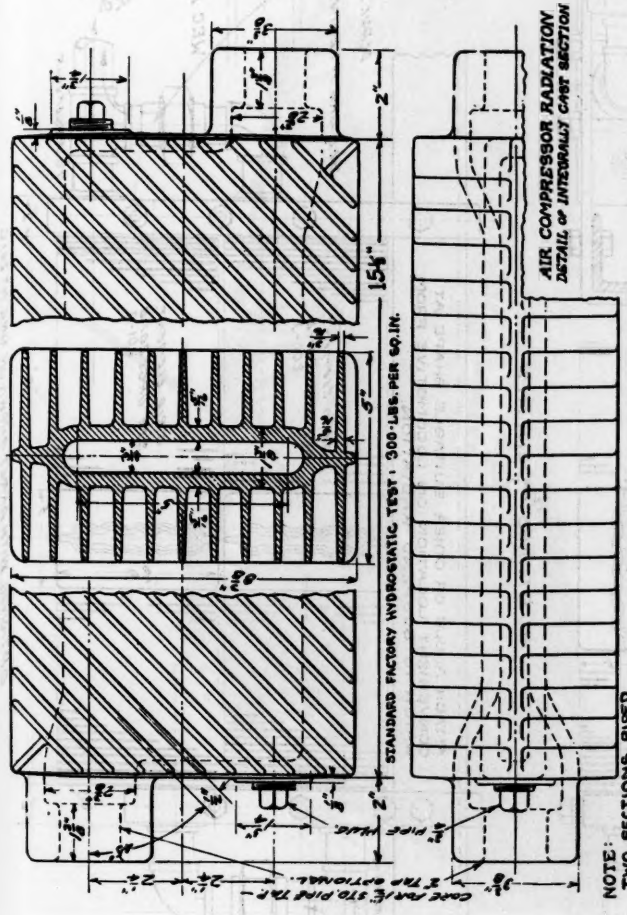

FIGURE 1.

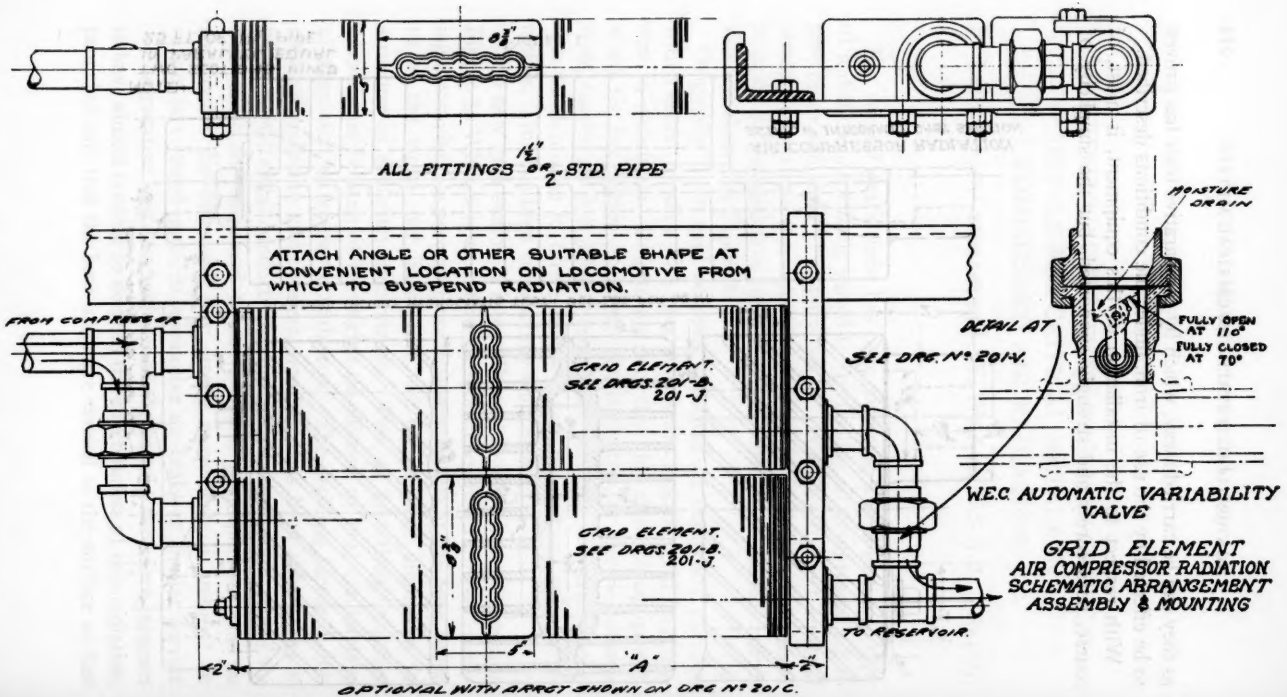
ALL FITTINGS 1/2" OR 2" STD. PIPE
ATTACH ANGLE OR OTHER SUITABLE SHAPE AT CONVENIENT LOCATION ON LOCOMOTIVE FROM WHICH TO SUSPEND RADIATION.
FROM COMPRESSOR
GRID ELEMENT SEE DRGS. 201-B. 201-J.
GRID ELEMENT SEE DRGS. 201-B. 201-J.
TO RESERVOIR
"A"
OPTIONAL WITH ARRGT SHOWN ON DRG. Nº 201 C.
MOISTURE DRAIN
DETAIL AT SEE DRG. Nº 201-V.
FULLY OPEN AT 110°
FULLY CLOSED AT 70°
W.E.C. AUTOMATIC VARIABILITY VALVE
GRID ELEMENT
AIR COMPRESSOR RADIATION
SCHEMATIC ARRANGEMENT
ASSEMBLY & MOUNTING

FIGURE 2.

FIGURE 2.

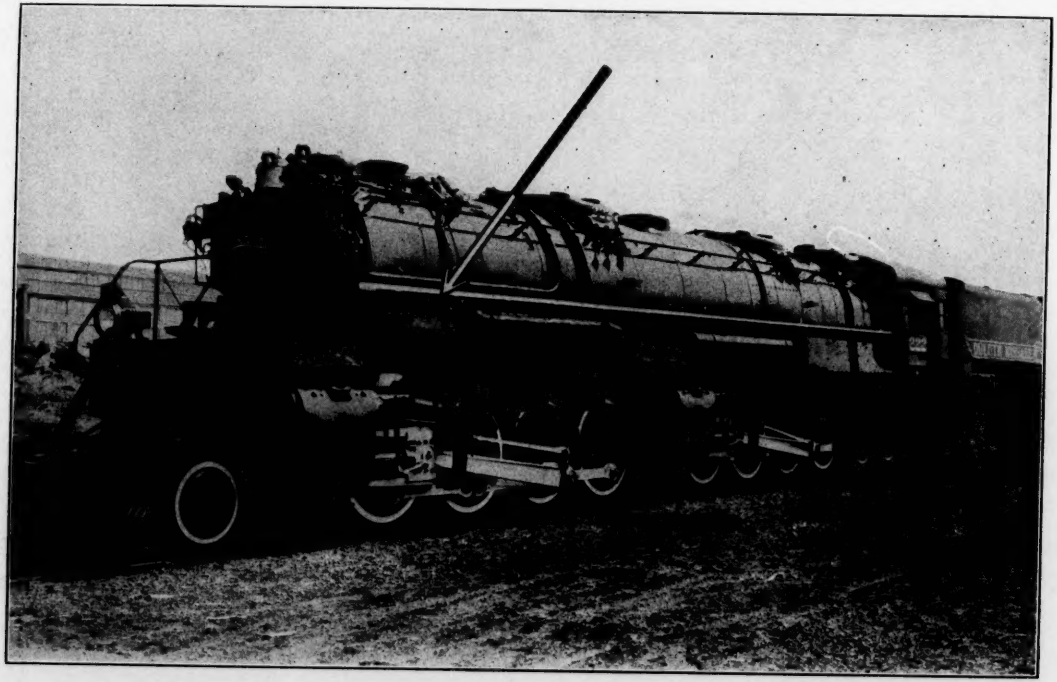

FIGURE 3.

the arrangement shown in Figure 2 is far superior to the miscellaneous bracketing required in mounting the conventional series of pipe coils. It will be noted that the sections are supported, for steam locomotive application, by a single angle bar, which is intended to reach from boiler bracket to boiler bracket as required for support of other structures such as the running board. This makes additional brackets or supports unnecessary.

The assembly of two or more grid sections in pairs allows an interesting range of radiation variability to meet extremely varied ranges of atmospheric temperatures. For instance, the installation shown in the accompanying photograph consists of two banks of two parallel sections each. For manual variability, a plug cock is inserted at the air entrance to one of the sections, leaving a free and unobstructed passage through the parallel section. The same end is gained automatically by means of a thermostatic valve. The automatic valve, however, is placed in the discharge end of the section to be cut out, because that valve must be actuated by the temperature of the air after passing through the radiation. This latter arrangement is shown in Figure 2.

There are consequential advantages in this type of radiation aside from the variability feature. Its compactness and neatness align with the modern trend of all types of locomotives. Accessibility to motion work and to the reservoirs is remarkably enhanced as compared with pipe coils which obstruct. Space can be found for practically any desired amount of additional radiation of this type, where additional pipe radiation may sometimes not be possible because of space limitation.

This radiation is standard equipment on new 5400 HP Diesel-electric freight locomotives and for that reason is operating on quite a number of trunk lines. It has been installed on steam locomotives by eight trunk lines. Its availability for use on shipboard where heat must be radiated to static or slow-moving ambient air would seem obvious. In such cases a sufficient number of sections to meet extreme high temperature requirement should be specified and installed; then, to prevent actual freezing of precipitated moisture under opposite extremes, sections would be cut out to leave only the desired amount of radiation. This can be effected in steps either manually or automatically, as shown and described.

DISCUSSION OF ARTICLE "FACTOR OF SAFETY AND WORKING STRESSES OF MARINE PROPULSION SHAFTING," BY R. MICHEL, FEBRUARY, 1942, ISSUE.

CAPTAIN H. C. DINGER, U.S.N., RETIRED.

This article is of special interest and value in showing the application of present existing data to the safe design of ship's shafting. Up to recent years, design of shafting was based upon the tensile strength of the material and an allowance of from 4 to 8 factor of safety was made upon this. This was a convenient method because about the only definite thing known about the material was its tensile strength. Yield point was somewhat variable and not always a definite figure. Since the yield point of steel is approximately one half the tensile strength, a so-called factor of safety of 6 on the tensile strength is really a factor of safety of only 3 on the yield point. Now as Mr. Michel has quite clearly pointed out, there are other stresses, usually variable, besides that caused by the engine torque transmitted through the shaft. Stresses due to vibration are the most important or destructive. When the nature of the vibration or the causes that produce the vibration are known, particularly the critical speed, then these can be allowed for by calculation with some reasonable approach to accuracy. However, there are various factors tending to cause vibration which may change during operation. To mention a few: (1) Lack of alignment. (2) Deterioration of foundations, allowing for movement. (3) Improper setting of propeller blades or damage to same. (4) Unbalance due to eccentric boring, etc. On cargo vessels, the status of loading or fluids in tanks or movement in heavy seas also may affect the tendency and nature of the vibration. Therefore although the calculation of the possible maximum stress, due to possible vibration, may be calculated for what may be estimated as being the most severe condition, there is still the

possibility that, due to some other changed condition which may not be allowed for, the actual stress may build up beyond this calculation. Therefore some allowance should be made for such uncertainty. Accordingly it is necessary to have some margin, even though all known possibilities of stress have been allowed for. The endurance limit for fatigue and corrosion fatigue is now approximately known for most shafting materials. This usually varies from ⅓ to ½ of the ultimate strength. If we allow a factor of safety of 3 on the tensile we would allow only for the normal torque and for fatigue. Then if we allow for maximum stress due to vibration we should be safe, provided that the design and construction of the shaft and its appendages does not produce any stress concentration beyond this. Stress concentrations are produced mainly at sharp corners at key ways, crank webs, coupling flanges, etc. If these are carefully filleted the stress concentration can be removed. However, stress concentrations are also caused by hidden locked up stresses set up in casting, forging or welding operations and not properly stress relieved and from hidden defects, small blow holes, metallic inclusions, etc. In sound, carefully processed material such hidden defects are usually absent, but there is no definite certainty of this. Therefore some allowance should be made. Coming back to our factor of 6, reduced to 3 by reason of yield point and endurance limit and expected vibration, if we make some allowance for imperfection in the material and inaccuracies in the machining of parts a factor of 3 is reduced to 2 without much actual margin.

Mr. Michel has pointed out that expected stresses in a reciprocating engine directly connected, may be of much greater magnitude than the shafting of a turbine, an electric drive, or reciprocating engine connected by means of an electric or fluid coupling. Here only the vibration due to propeller and shafting itself would have to be allowed for. It has been past practice, going back for nearly a century, to allow a double bending moment on the outboard shafting. This originally was a guess to allow for difficulties and deterioration due to shaft operating in water, especially salt water. We now know why this was wise since our corrosion fatigue discoveries have shown that the fatigue limit in the presence of salt water is considerably different from that in air. Doubling the bending moment was a rather generous allowance,

but doing it was on the side of safety and avoided many shaft casualties.

Until recently the danger of sharp corners was not properly sensed. As an engineer, nature loves adequate fillets and hates sharp corners. Sharp corners are perhaps more responsible for casualties in stressed machinery parts than any other particular point of bad design.

This whole matter shows more definitely that the so-called factor of safety is still a factor of ignorance and that making a good guess and doubling it was and still may be good strategy. Also it shows that the adage of "What you don't know won't hurt you" is not always good engineering.

NOTES.

INDEX TO NOTES.

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HIGH-PRODUCTION HIGH-ECONOMY METHODS FOR METAL PARTS.

This article by D. Basch, consultant on materials and processes, General Electric Company, appeared in the September, October and December, 1941, issues of the General Electric Review.

PART I: CASTINGS.

In selecting the material and the manufacturing process for any particular application especially where high-production methods are to be employed, the criteria for good engineering are suitability for the purpose and maximum economy.

Each part, by itself and when assembled with other parts, must meet all the physical, chemical, electrical, and mechanical requirements of service.

The over-all cost of the finished article, comprising basic material, fabrication of the part (that is, casting, punching, forging, etc.), finishing to final dimensions and condition, and assembly, must represent the maximum salable and competitive value per dollar expended.

The selection of material and manufacturing process must always be a matter of balance. Deciding on either the material or the process before giving consideration to the other is a risky procedure, for the choice so made may later be found to be inferior to some other choice arrived at by taking all the requirements into account. A number of materials may fulfill the mechanical and physical requirements of the design, but not all of them may lend themselves equally well to the most economical production method. And not all production methods have the same effect on the properties of even the same material.

The material largely governs the dimensioning of the sections and the general design, because of the characteristic physical properties of the material being used. However, the design is also affected by the process, since for every manufacturing process there is a most effective design, usually differing in some details from all others. To change the method of manufacturing a part that has been designed for manufacture by some other method, without changing the design, usually adds to the difficulty of manufacture and cost of the part, or sacrifices some of the valuable features of the initial process. The data given in this article deal with high-production high-economy methods for metal parts and their application to various materials, but not with the materials themselves.

Castings are used in preference to wrought materials where irregularity of outline, variability of section, size, or other considerations make too difficult or too costly the use of wrought material, whether formed or fabricated in one piece or assembled from several pieces. However, wrought parts, if they are practicable, are as a rule stronger and more dependable than castings; and the cost of cast metal (unmachined) is higher than that of the corresponding wrought material before fabrication.

SAND CASTINGS.

Sand castings are still the most common form of castings. They permit the use of the lowest cost tools and entail the shortest time to get into production. They are more flexible as to design, choice of material, and alterations after tools have been made, but they require more direct labor in the foundry and machine shop, are rougher in appearance, and are more variable in structural density and physical properties than metal-mold or plaster-of-Paris castings.

Sand castings are subject to certain defects which, in a well-designed

casting, are controllable by proper foundry technique, but are not wholly predictable or preventable. Not all of these defects can be detected by visual inspection; some may be hidden below the surface. Therefore the designer must accept as an always present possibility certain short-comings in sand castings and must make allowances for them in his design. There may be internal blow holes or shrink holes in any sand casting; therefore, a higher factor of safety must be used for sand castings than for other types of castings, or wrought sections, especially where the part is highly stressed and there is an important responsibility for maintenance of service and safety of operation.

In any sand casting there may be surface imperfections, and variations in wall thicknesses because of core shift, etc. Therefore, in such a casting more stock must be left for machining, and the minimum wall thickness must be heavier than in other castings or wrought sections. Many surfaces which come sufficiently smooth and level in other types of castings or wrought sections must be machined for appearance or assembly fit with some other part in the case of sand castings. Dimensional tolerances must be more liberal, in general at least $\pm 1/32$ inch for thin sections and $\pm 1/16$ inch for heavier sections (cast steels require more). Where closer tolerances are required, sand castings must be machined.

Therefore sand castings are likely to cost more than other forms of castings if there is involved considerable machining which would be unnecessary on other castings.

Plaster-of-Paris Castings.

A process, intermediate between sand and metal-mold casting, which has found considerable commercial use during the past few years, is known as the "plaster-of-Paris" process. Castings produced by this method are made in baked plaster-of-Paris molds, and offer the same close tolerances as metal-mold castings, at considerably lower tool cost although at a higher piece price than sand castings before machining. The process is particularly suitable for moderate-production parts which would require considerable machining if made in sand and on account of limited production would not justify the high tool cost of metal molds. They are more competitive with metal-mold castings when brass or bronze is the casting metal than when this metal is aluminum.

Because the low thermal conductivity of a plaster-of-Paris mold, compared with that of a sand or a metal mold, keeps the casting metal fluid much longer in the mold, sections can be cast much thinner in plaster-of-Paris molds than in either sand or metal molds. Also, there is less risk of internal porosity than in sand castings. However, the structural strength of castings made in plaster-of-Paris molds is likely to be somewhat lower than that of metal-mold or sand castings. Plaster-of-Paris mold castings have been used in large quantities with good results for plumbing fixtures; railroad, automotive, and domestic hardware; ball races; gears of all sorts; handles, cams, and levers; covers and boxes; brush holders, terminals, etc.

The plaster-of-Paris process is usually limited to metals with a melting point not exceeding about 2100 F. (except magnesium) but special processes are commercially available to cast higher-melting-point metals to 3000 F. like stainless steels, etc.

Metal-Mold Castings.

Metal-mold castings are of the following types:

(a). Permanent-mold castings (including slush castings).

(b). Semipermanent-mold castings.

(c). Castings with external pressure.
(1). Die castings.
(2). Cold-chamber pressure castings.
(d). Centrifugal castings.

All metal-mold castings have higher strength, better surface appearance, and closer tolerances than sand castings of the same metal, but they entail higher tool cost. Owing to the close tolerances and good surface of metal-mold castings, they usually obviate costly machining operations necessary with sand castings, except for very close tolerances. They frequently cost less than forgings requiring considerable machining, or drawn parts necessitating more than one anneal between draws, or even screw-machine parts where much of the material is lost in machining.

The question of plastics versus metal-mold castings is outside the scope of this article, but the following general statements will aid in making a choice.

Die castings and cold-chamber pressure castings have the following advantages:

Strength (tensile, compression, bending, and impact).
Immunity to deterioration by heat.
Electrical and heat conductivity.
Dimensional accuracy.
Lower die cost (original and maintenance).
Higher rate of production.

Plastics have these advantages:

Less weight.
Better smoothness and appearance of surface.
Color, gloss. Transparent and translucent effects.
Insulating properties.

Metal-mold castings should be considered in every case where production is high or even moderately high (in one case, zinc die castings with a yearly production of 150 have cost less than machined gray-iron castings), and also where the mechanical requirements are not beyond the possibilities of this type of casting.

The final selection of the metal-mold casting process, in competition with sand casting or any other method of manufacture, will depend on the best balanced combination of:

(a). Suitability of the material under consideration and physical characteristics imparted to it by the process.
(b). Competitive and advertising advantages through the use of the process.
(c). Cost of tools and of each piece in a finished state, inclusive of all machining.
(d). Total saving in cost of all finished pieces during the period allowed for the liquidation of tools.

The length of time allowed for liquidation of tools—that is, for cancellation of the tool cost out of the savings effected in the manufacture of the finished part—varies with the job. In the case of an order not likely to be repeated, the period should be the life of the order. In the case of a standard part, the period should depend on the prospective life of the design and on the engineering and advertising advantages derived from the use of the process.

Even after the economic and mechanical advantages of one or another form of metal-mold process have been definitely established, the designer should make sure that the design is definitely settled and not subject to early change owing to shifting sales sentiment or to service troubles. The heavy investment in mold cost is likely to militate against an otherwise highly desirable change, or at least to load the development account unduly.

The design should be laid out for the selected form of metal mold, but if there is any uncertainty about the stability of the design it is advisable to handle production during the introductory period with sand castings or in some other less restricting form.

Permanent-Mold Castings.

In the permanent-mold casting method, fluid metal is poured by hand into metal molds, and around metal cores, without external pressure. The molds are usually held together by C-clamps, although in some cases they are closed and opened by a screw or toggle.

Metals suitable for this type of casting are: lead, zinc, aluminum and magnesium alloys, certain bronzes, and cast iron.

For making iron castings of this type, turntables on which a number of metal-mold units are mounted are frequently employed; and the individual operations—such as coating the mold, placing the cores, closing the mold, pouring, opening the mold, and ejection of the casting—are performed as each mold passes certain stations.

Zinc-aluminum permanent-mold castings are usually slush castings. Metal molds are employed. After the molds have been filled with molten metal and as soon as the outer skin of the casting has solidified, the mold is up-ended and the still-liquid metal on the inside is allowed to run out, thus leaving a hollow thin-walled shell casting. The thickness of the wall can be controlled by the pouring temperature, the interval of time between pouring in and out, etc. The walls, of course, are always irregular. In addition to zinc, some lead and aluminum alloys are suitable for the making of these castings. They are often used for lighting fixtures, spouts, etc.

The permanent-mold method provides castings having these advantages:

(a). Dense fine-grained structure, free from shrink holes or blowholes.

(b). Relatively low tool charges incurred.

(c). Better surface and closer tolerances than provided by the sand-cast method.

On the other hand, the permanent-mold process has these limitations:

(a). Inability to maintain as close tolerances and as thin sections as will the die-, pressure-, or plaster-of-Paris casting methods.

(b). Yellow brasses, which are high in zinc, are difficult to utilize because of zinc oxide fouling the molds or dies.

Semipermanent-mold Castings.

This method is the same as that for permanent-mold castings except that sand cores are used at some points instead of metal cores. The tool cost is lower than for permanent-mold castings with metal cores. The metals suitable for casting by this method are the same as those for the permanent-mold method.

The semipermanent-mold process is particularly applicable where cored openings are so irregular in shape or undercuts that metal cores would be too costly or too difficult to handle.

The disadvantage of the method lies in the fact that the structure of the metal around the sand cores is like that of a sand casting. The advantages of permanent-mold casting as to tolerances, density, appearance, etc., exist only in the section cast against the metal mold.

Castings with External Pressure (Die and Cold-chamber Pressure).

In both these types, highly fluid metal is forced under considerable outside pressure into metal molds, which are usually artificially cooled to speed production by hastening solidification of the casting and removal from the mold.

Die Castings—

Die castings are produced in machines which consist basically of a basin holding a considerable quantity of molten metal (enough for several hours' production and continually replenished), a metallic mold or die, and a metal-transferring device which automatically withdraws a certain amount of molten metal from the basin and forces it under external pressure into the die.

Two forms of die-casting machines are in general use. Lead, tin, and zinc alloys containing aluminum are handled in the so-called piston machine (Figure 1). Aluminum alloys, pure zinc, or zinc alloys free from aluminum

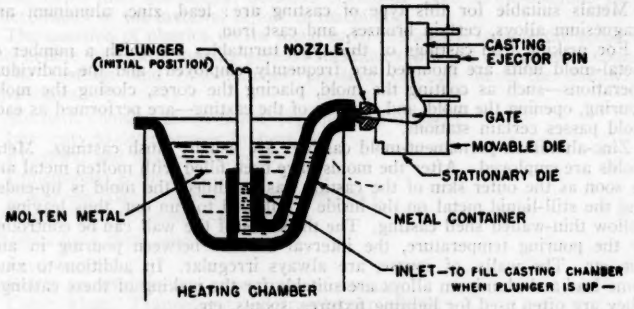

Fig. 1. Typical piston machine. The plunger, heating chamber, metal chamber, and die carriage are parts of the same machine

require a different type of casting machine since these materials rapidly attack the iron in the piston and cylinder and destroy the required close fits.

Pressures back of the metal in the piston machine range from a few hundred to 5000 pounds per square inch. The best practice for zinc-aluminum alloys is to use a minimum of about 1000 pounds per square inch.

The gooseneck machine (Figure 2) was developed primarily for aluminum alloys and is limited in pressure back of the metal to a maximum of about 700 pounds (350 to 550 pounds per square inch on the average). It is sometimes used for zinc-aluminum alloys, especially for large castings but, owing to the lower pressure back of the metal, the structure is likely to be less dense than when made in the piston machine. It is seldom used for magnesium alloys.

Cold-chamber Pressure Castings—

Cold-chamber pressure castings are produced in machines (Figure 3) which are fundamentally different from the die-casting machines shown in Figures 1 and 2 in that the molten-metal reservoir is separated from the casting machine, and just enough metal for one shot is ladled by hand into a small chamber, or pouring well, from which it is forced into the die under high pressure. Pressures back of the metal range from a few thousand to 10,000 pounds per square inch and more. The process is applicable to aluminum alloys, magnesium alloys, zinc alloys (although the commercial aluminum-bearing zinc alloys are usually handled in standard piston machines which can supply enough pressure for all purposes at higher production speed), and even high-melting-point alloys like brasses and bronzes, since the pouring well, cylinder, and piston are exposed to the high temperature for only a short time.

Selection of Casting Metal.

Compared to zinc, aluminum has the advantages of lighter weight; greater corrosion resistance to certain corroding elements, particularly food, fruit acids, etc.; and ability to withstand higher temperatures. On the other hand, commercial zinc alloys have higher strength and ductility (although some aluminum alloys have been developed that make castings which compare favorably with zinc alloys) and greater resistance to shock (except at freezing temperature). They can be cast in thinner sections and with sharper

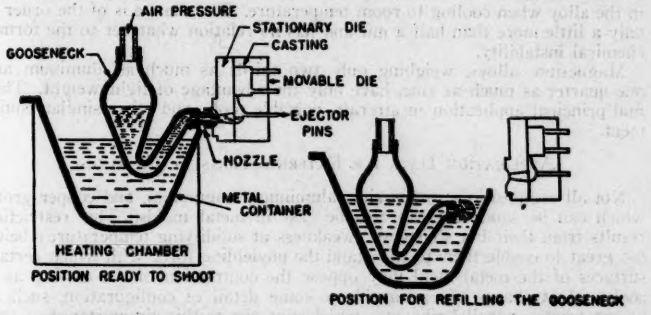

Fig. 2. Typical gooseneck machine, in the casting and the gooseneck-filling positions. The gooseneck, metal container, heating chamber, and die carriage are parts of the same machine

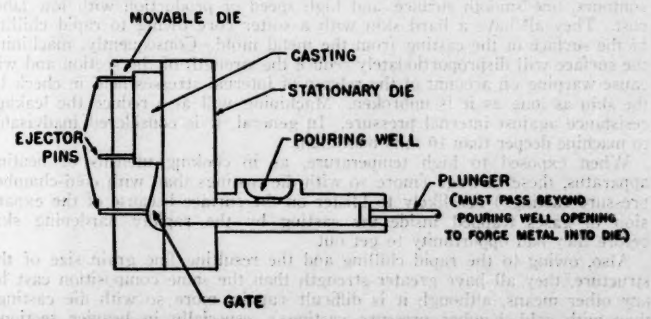

Fig. 3. A type of cold-chamber pressure-casting machine. The plunger, cylinder, and die carriage are parts of the same machine. The melting pot and metal container are separate

outlines and closer tolerances; they require less costly dies and less die maintenance; and they can be plated easily. In general, although zinc on the volume basis costs as much or more than the aluminum usually employed, if zinc is suitable for the service to which the castings are subjected and if full advantage in sectioning is taken of its high physical properties and high fluidity, zinc castings will probably be cheaper than aluminum castings.

In past years zinc-alloy die castings were subject to considerable criticism because of structural instability in that, especially in humid atmosphere, they

would after some time be likely to crack, swell, and even disintegrate. Metallurgical research has definitely determined that the trouble resulted from the presence of certain impurities in the zinc and the alloying constituents. Modern zinc die castings, produced under adequate metallurgical control, are perfectly reliable and safe, as demonstrated by their service record during the last ten years. There is, however, usually a very small change in dimensions during the first five weeks of air exposure after the castings have been taken out of the die (which shrinking may be hastened through a short-time artificial aging, and in either case stops after five weeks' air aging or the artificial aging). This shrinking takes place because of phase adjustments in the alloy when cooling to room temperature. The change is of the order of only a little more than half a mil and has no relation whatever to the former chemical instability.

Magnesium alloys, weighing only two thirds as much as aluminum and one quarter as much as zinc, have only the advantage of light weight. They find principal application in aircraft, portable tools, and other similar equipment.

Application Data for External-pressure Castings.

Not all compositions of the zinc, aluminum, magnesium, and copper group which can be sand cast can also be cast in metal molds. This restriction results from their hot shortness (weakness at solidifying temperature) being too great to enable them to withstand the unyielding force with which certain surfaces of the metal mold may oppose the contraction of the casting as it cools. Most shapes of castings have some detail of configuration, such as bosses, prongs, parallel ribs, etc., which give rise to this circumstance.

All metal-mold external-pressure castings share certain properties, although to a varying degree. They all have close tolerances, sharp outlines and contours, fine smooth surface, and high speed of production with low labor cost. They all have a hard skin with a softer core owing to rapid chilling of the surface of the casting from the metal mold. Consequently, machining the surface will disproportionately reduce the strength of the section and will cause warping on account of the release of internal stresses held in check by the skin as long as it is unbroken. Machining will also reduce the leakage resistance against internal pressure. In general, it is considered inadvisable to machine deeper than 10 mils maximum.

When exposed to high temperature, as in cooking utensils or heating apparatus, these castings (more so with die castings than with cold-chamber pressure castings) are likely to blister on the surface because of the expansion of gases trapped inside the casting by the rapidly hardening skin before they had opportunity to get out.

Also, owing to the rapid chilling and the resulting fine grain size of the structure, they all have greater strength than the same composition cast by any other means, although it is difficult (again, more so with die castings than with cold-chamber pressure castings), especially in heavier sections, to avoid occasional internal porosity.

Aside from these characteristics common to both methods of casting, there are certain fundamental differences between them, particularly between the product of the gooseneck machine and that of the cold-chamber machine.

In the gooseneck machine (Figure 2), the gooseneck which dips the molten metal out of the metal container and transfers it to the die is constantly immersed in the molten metal. The gooseneck is made of cast iron to withstand the pressure back of the metal at the high metal temperature. The metal container is also usually of iron. At the temperature of molten aluminum, the aluminum strongly attacks the iron in the gooseneck and metal container with the result that the aluminum gradually absorbs an

TABLE I

TOLERANCES FOR METAL-MOLD CASTINGS

(These data should be used for general guidance only. Actual design conditions will affect possible minima or maxima.)

Manufacturing Method	Metal	Tolerances Within Solid Die	Minimum Wall Thickness in Inches (See Note 1)	MINIMUM HOLE—DIMENSIONS: Maximum Diameter in Inches	MINIMUM HOLE—DIMENSIONS: Maximum Depth by Diameters	Minimum Draft per Side Per Inch of Depth of Side Wall or Holes, Inches per Inch.
		Remarks: Tolerances should be as liberal as possible in the interest of low die and casting costs. Wherever permissible they should be greater than those given below. Still closer limits than those given are obtainable, but only at higher costs. Tolerances affected by moving members must be somewhat greater (across parting lines, etc.).	Remarks: Varies with alloys. (Aluminum-silicon alloys, for instance, will cast in thinner sections than aluminum-copper alloys.)	Remarks: Cores for casting holes produce a beneficial chilling effect. Therefore, where possible, all holes should be cored, except when so small or deep that cores may be warped or bent under the shrinkage stresses of the freezing metal, or when drilling or punching is cheaper.		Remarks: Draft per side on walls where metal shrinks away from die could be somewhat smaller. Liberal draft results in superior surface finish.
Die and Cold-chamber Casting	Magnesium Alloys	±0.0015 in. per inch, but at least ±0.003 in.	0.050 for small sections. More for larger sections.	Smaller than 1/32 1/32 to 1/4 1/4 to 1	Not cored 3 times 3 to 5 times	0.010
	Aluminum Alloys	±0.0015 in. per inch, but at least ±0.003 in.	0.035 for small sections. More for larger sections.	Smaller than 1/32 1/32 to 1/4 1/4 to 1	Not cored 3 times 3 to 6 times	0.010
	Zinc Alloys	±0.001 in. per inch, but at least ±0.0025 in.	0.020 for small sections. More for larger sections.	Smaller than 1/32 1/32 to 1/4 1/4 to 1	Generally not cored. 3 to 8 times 6 to 8 times	0.005
	Brass and Bronze	±0.003 in. per inch, but at least ±0.005 in.	0.050 for small sections. More for larger sections.	Smaller than 1/16 1/16 to 1/4 1/4 to 1	Not cored. 2 times 2 to 4 times	0.015
Permanent-mold Casting	Magnesium Alloys	±0.0015 in. per inch, but at least ±0.010 in.	0.1875 (regardless of whether surface is rough or smooth.)	Smaller than 1/4 1/4 to 1/2 1/2 to 1	Generally not cored. 3 times 3 to 6 times	0.015
	Aluminum Alloys	±0.0015 in. per inch, but at least ±0.010 in.	0.125 (0.090 where at least one side can be reasonably rough.)	Smaller than 1/4 1/4 1/4 to 1	Generally not cored. 3 times 3 to 6 times	0.015
	Bronze	±0.005 in. per inch, but at least ±0.010 in.	0.075 for small sections. More for larger castings.	Smaller than 1/8 1/8 to 1/4 1/2 to 1	Generally not cored. 2 times 2 to 4 times	0.020

NOTE 1: The minimum wall section that can be cast with different alloys and by different processes is not absolutely fixed. It depends on the size and design of the casting, on the location of the section with reference to heavier adjacent sections, on the die, the alloy, type of machine, and the pressure applied. In general, the lower the melting point and the more fluid the metal, and the shorter the distance the metal must flow between the chilling walls of the die or mold, or the faster it traverses the distance, the thinner the wall may be. There is practically no limitation on casting heavy wall thickness as may be encountered in commercial applications. Sections somewhat heavier than minimum castable are recommended (especially for die and pressure castings) when castings are to be plated, as they hold greater promise for smooth surface.

FINISHES: Metal-mold castings can be finished with three different finishes, as follows, and should be marked on drawings to designate type of finish desired.

No marking—Commercial: Standard finish produced by commercial, but carefully controlled, routine.
Decorative: (Required for plating) Free from flow marks and from swirls and other surface imperfections.
Poorer than commercial; suitable for enterprised or painted surfaces.

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TOLERANCES FOR METAL-MOLD CASTINGS

(These data should be used for general guidance only. Actual design conditions will affect possible minima or maxima.)

Manufacturing Method	Metal	Tolerances Within Solid Die	Minimum Wall Thickness in Inches (See Note 1)	MINIMUM HOLE—DIMENSIONS		Minimum Draft per Side Per Inch of Depth of Side Wall or Holes Inches per Inch.
				Maximum Diameter in Inches	Maximum Depth by Diameters	
		Remarks: Tolerances should be as liberal as possible in the interest of low die and casting costs. Wherever permissible they should be greater than those given below. Still closer limits than those given are obtainable, but only at higher costs. Tolerances affected by moving members must be somewhat greater (across parting lines, etc.).	Remarks: Varies with alloys. (Aluminum-silicon alloys, for instance, will cast in thinner sections than aluminum-copper alloys.)	Remarks: Cores for casting holes produce a beneficial chilling effect. Therefore, where possible, all holes should be cored, except when so small or deep that cores may be warped or bent under the shrinkage stresses of the freezing metal, or when drilling or punching is cheaper.		Remarks: Draft per side on walls where metal shrinks away from die could be somewhat smaller. Liberal draft results in superior surface finish.
Die and Cold-chamber Casting	Magnesium Alloys	±0.0015 in. per inch, but at least ±0.003 in.	0.050 for small sections. More for larger sections.	Smaller than $\frac{1}{32}$ $\frac{1}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored 3 times 3 to 5 times	0.010
	Aluminum Alloys	±0.0015 in. per inch, but at least ±0.003 in.	0.035 for small sections. More for larger sections.	Smaller than $\frac{1}{32}$ $\frac{1}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored 3 times 3 to 6 times	0.010
	Zinc Alloys	±0.001 in. per inch, but at least ±0.0025 in.	0.020 for small sections. More for larger sections.	Smaller than $\frac{1}{32}$ $\frac{1}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Generally not cored. 3 to 8 times 6 to 8 times	0.005
	Brass and Bronze	±0.003 in. per inch, but at least ±0.005 in.	0.050 for small sections. More for larger sections.	Smaller than $\frac{1}{16}$ $\frac{1}{16}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored. 2 times 2 to 4 times	0.015
Permanent-mold Casting	Magnesium Alloys	±0.0015 in. per inch, but at least ±0.010 in.	0.1875 (regardless of whether surface is rough or smooth.)	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{2}$ to 1	Generally not cored. 3 times 3 to 6 times	0.015
	Aluminum Alloys	±0.0015 in. per inch, but at least ±0.010 in.	0.125 (0.090 where at least one side can be reasonably rough.)	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ to 1	Generally not cored. 3 times 3 to 6 times	0.015
	Bronze	±0.005 in. per inch, but at least ±0.010 in.	0.075 for small sections. More for larger castings.	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{2}$ to 1	Generally not cored. 2 times 2 to 4 times	0.020

NOTE 1: The minimum wall section that can be cast with different alloys and by different processes is not absolutely fixed. It depends on the size and design of the casting, on the location of the section with reference to heavier adjacent sections, on the die, the alloy, type of machine, and the pressure applied. In general, the lower the melting point and the more fluid the metal, and the shorter the distance the metal must flow between the chilling walls of the die or mold, or the faster it traverses the distance, the thinner the wall may be. There is practically no limitation on casting heavy wall thicknesses as may be encountered in commercial applications. Sections somewhat heavier than minimum castable are recommended (especially for die and pressure castings) when castings are to be plated, as they hold greater promise for smooth surface.

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Poorer than commercial; suitable for unexposed or painted surfaces.

unduly large amount of iron. The presence of this absorbed iron affects the castability of the aluminum and the ductility, machinability, shock resistance, etc. of the castings. It is quite difficult in a gooseneck machine to keep the iron content in the aluminum at its starting figure.

In the cold-chamber machine, the metal container is separate from the remainder of the machine. A hand ladle dips enough for one shot out of the container and the pouring well is charged only with the contents of the ladle. Between shots neither ladle nor pouring well is in contact with molten metal. For this reason it is much easier to minimize the iron content, which is particularly important when specifications demand low iron in aluminum castings.

The other chief difference between the methods lies in the pressure back of the metal when the die is completely filled. The greater the pressure back of the metal, the greater the compressive force on the metal as it passes through the pasty stage, the greater the force to compact the structure and to press the hot metal through narrow channels, into sharp corners, crevices, etc.

In the gooseneck machine, the pressure is limited by the mechanical strength of the cast-iron gooseneck at the temperature imparted by the molten aluminum (around 700 C.), 700 pounds per square inch being as high as is safe. In cold-chamber pressure-casting machines, there is practically no pressure limitation, pressures as high as 16,000 or even 20,000 pounds per square inch being employed in some cases. Usually, however, lower pressures, of the order of 3000 to 10,000 pounds per square inch, are used to facilitate the mechanical problem of making the machine heavy enough to provide the locking and holding power to keep the two die halves together without opening up under the tremendous impact of the injected metal.

Not all cold-chamber pressure castings are superior to gooseneck or piston-machine die castings, except when made under expert metallurgical and production control, with careful consideration to venting (to drive the air out ahead of the incoming metal), gating, and die design in general.

Because of their uncertain structural condition, gooseneck castings should never be used in any application which bears serious responsibility for maintenance of service or protection against trouble, but cold-chamber pressure castings may be used for such service if produced under the conditions mentioned in the preceding paragraph.

There is another important difference between the ordinary die-casting machines (both piston and gooseneck) and the cold-chamber machines in that the casting mechanism of the die-casting machines is constantly immersed in the hot molten metal, whereas in cold-chamber pressure machines it is immersed only for short, intermittent periods. As a result, neither the standard piston nor gooseneck machines can be used for the higher-melting-point alloys, like brasses and bronzes, whereas cold-chamber pressure machines can be.

Cold-chamber pressure-cast brasses and bronzes have not yet found the same wide popularity as die castings or cold-chamber pressure castings of zinc or aluminum, although excellent products have been turned out. The main difficulty lies in the high cost of the dies, since the tool-steel industry has not yet been able to produce a steel for the dies which will last as long against the high temperature at which the cuprous alloys are cast as die steels for aluminum or zinc. Plaster-of-Paris or permanent-mold castings are still competing favorably with cold-chamber pressure-cast brass or bronze, except where production is so large, and saving in machining because of closer tolerances so considerable, that the high cost of molds for the cold-chamber pressure castings can be absorbed.

The tolerances and general relative characteristics of various casting methods are given in Tables I and II.

TABLE II

RELATIVE CHARACTERISTICS OF DIFFERENT CASTING METHODS

(Numbered in order of preference)

Casting Process	Sand	Plaster of Paris	Centrifugal	Permanent-mold	Die	Cold-chamber Pressure	
Porosity	6	2–1	1–2*	3–4†	5	4–3	
Surface	6	1	5–4*	4–5†	2–3	3–2	
Sharpness of Outline	6	3	4–5*	5–4†	2	1	
Tolerances							
Strength (Solid Metal)	5–6	6–5	3*	4†	2–1	1–2	
Thin Section	5	1	6	4	3–2	2–3	
Tool Cost (Pattern or Molds)	1	3	2	4	5–6	6–5	Tool cost and cost per casting depend on number of patterns per plate or impressions in die; the more castings that can be made at one operation, the lower the labor cost per piece, with inversely increasing tool cost. Sand and plaster of Paris patterns lend themselves more economically to multi-impressions than metal molds.
Speed of Production and Labor Cost per Casting	On basis of most economical tool setup (as to number of impressions on one pattern plate or in one die) for comparative production quantities.						
	For small and moderate production including setting up of die.						
	1	2	4	3	5–6	6–5	
	For large production:						
	5	6	4	3	1–2	2–1	
Possibility to Save Machining	6–5‡	3	5–6‡	4	2–1	1–2	

* In metal left after removal of drossy material from inside of wall.
† Only in material next to metal mold in case of semipermanent molds.
‡ May be reversed in certain cases.

The effect of process on the strength of the material is indicated qualitatively in Table II in the line "Strength (solid metal)." These data should be considered in conjunction with the data on porosity in the same table because, for instance, a cold-chamber pressure casting of a material of relatively low unit strength may have higher actual strength than a die casting of a material of higher unit strength, and certainly will be more dependable because of the greater likelihood of internal porosity in the die casting.

Because of the steadily growing interest of engineers in die casting and cold chamber pressure casting, further information* will be given about some common design features with respect to castings made by these processes.

Dies usually comprise two blocks of steel (each containing a part of the cavity), which are locked together while the casting is being made and drawn apart when it is ready for ejection. One half of the die (next to the injector nozzle) is stationary and the other half moves on a carriage.

As the die opens, the casting remains in the movable half of the die. This half often contains core pins or other male portions upon which the casting shrinks in cooling. Ejector pins push the casting off these pins and projections, and free of the die.

Aside from changes in dimensions of the die blocks resulting from heat expansion and contraction and from minor wear on die surfaces, and under reasonably constant casting conditions, the dimensions of the cavity, and of the casting formed within it, remain substantially fixed.

When convenient, cores should have their axes at right angles to the parting face, parallel to the direction of motion of the die blocks, as they are then most easily removed. However, cores can be pulled at any angle.

Threads—

In general, either inside or outside threads are readily included in die or cold-chamber-pressure castings, but it is usually cheaper and more satisfactory to tap all holes which are to be threaded.

Outside threads are usually formed by a split section of the die, which results of course in a small fin where the split or parting is made. The thread must be subsequently chased if a close fit with the mating part is required.

Die-cut threads are more nearly perfect in form, size, and finish than are threads that are die cast or cold-chamber pressure cast, unless the cast threads are made with extra metal to be removed in a chasing operation. Many threads are used as cast, or with little chasing, except for rough-fin removal, where exceptional accuracy is not required. Shrinkage of the piece causes an error in pitch, but usually this is not significant unless the thread is unusually long.

Small holes to be tapped are usually cored to the root diameter of the thread, minus the draft or taper required, and may then require no drilling before tapping.

Inserts—

Die castings and also cold-chamber pressure castings sometimes employ cast-in inserts of dissimilar metals, or of nonmetallic elements, to impart locally to the casting certain properties which the cast alloy itself does not possess, such as higher strength, greater hardness and wear resistance, special electric or magnetic paths, or superior bearing qualities. The inserts are placed in the die before the casting is made, and must be positioned securely by the die. The insert is usually placed in the hot die by hand. This operation lengthens the cycle and reduces the production rate for which

* Quoted in part from the book *Die Castings* by Herbert Chase, John Wiley & Sons, New York, 1934.

† Only in material next to metal mold in case of ...
‡ May be reversed in certain cases.

reason inserts are used only when the increased cost is justified by the benefit obtained. The most common insert is a screw-machine product of steel or brass, but stampings, forgings, and even sandcast or die-cast inserts have been used to advantage. Inserts of metal other than that of the casting itself may give rise to electrolytic action between the two metals when an electrolyte is present. Resulting corrosion may loosen the insert or cause other trouble.

Inserts are usually knurled on the surface in contact with the metal cast around them, or undercut or provided with projections or holes which anchor them securely when metal is cast around them, to prevent them from turning or pulling out of the casting. When plated inserts are to be used in zinc castings, they should never be tin- or cadmium-plated, as such plates would seriously affect the chemical stability of the casting.

Bearings and bushings, if accurately machined before insertion, require little or no machining after casting in place, as they can be positioned quite accurately on cores or fixed pins. At most, only little reaming of the bore should be required after the bushing is cast in place. As some die-casting alloys and cold-chamber pressure alloys, especially zinc-base, have good bearing qualities, bushing inserts are not always required as a bearing.

Bearing inserts may be of almost any metal, such as graphited or porous bronze (porous-bronze inserts should not be oil-filled until after the casting has been made) or hardened steel, or may even be of wood, or such materials as molded phenolics, especially when used with zinc alloy. The molten metal entering the mold solidifies quickly and, in the case of wood inserts, barely discolors their surface. Hardened-steel inserts may be cast in without losing their temper.

Fillets—

As in all forms of castings, sharp corners in die and cold-chamber pressure castings, at the junction of sections disposed at different angles, are preferably to be avoided. Such sections should be joined by fillets, especially where these junctions are to be subjected to stresses. Sharp corners in molds may retard metal flow or cause eddies and trap air, and thus may be disadvantageous from the casting standpoint. When assembly of mating parts causes a normal fillet at an outside corner to interfere, a fillet recessed below the level of the surfaces may sometimes be employed.

Ribbing—

It is desirable that thin sections of considerable area, especially when flat, be well ribbed, not only to gain stiffness and to minimize warpage, but also to provide more feeder channels of larger sectional area through which the metal can flow in filling the die. Without such channels, a large flat surface may not fill out, especially when the die is cold, and the percentage of rejected castings will be increased accordingly.

Cored and Other Holes—

When there are to be holes in a die-cast or cold-chamber pressure-cast part, first consideration should be given to coring them. However, it does not always pay to core small holes, as drilling or punching may prove to be cheaper than coring.

Although the core must clear the casting, it need not be straight, and does not have to be withdrawn in a straight line. It can be curved in a true circular arc and rocked into and out of position, or it may have loose pieces which come out with the casting and are subsequently knocked out and placed in the die again for the next casting.

As metal enters the die under high pressure and at high velocity, a slender core may be easily bent or broken, if it is supported only at one end. A

through hole, in such position that the core pin can be supported at both ends, tends to avoid bent cores and holes that are out of alignment or off center. For similar reasons, it is best to avoid intersecting cores, if possible, although they are often used successfully.

The core produces a beneficial chilling effect, similar to that of other die parts, and in so doing extends this action to a larger part of the casting.

Special Cores—

Where undercuts are required, use may be made of collapsible cores which are in several sections so designed and assembled that the key section can be withdrawn easily, leaving the others then free to be removed. In other cases, straight cores may be combined with one or more loose pieces for the undercuts which are knocked out when the main core has been withdrawn.

Crooked cores are sometimes made up from loose pieces or knockouts designed to clear when removed separately but not as an assembly. A kettle spout, illustrated in Figure 4 is a good example. An example of a collapsible-core arrangement is shown in Figure 5.

In other cases, crooked channels from which cores could not be withdrawn are made by using a drawn tube, bent to the desired shape, as an insert and casting it in place. This is sometimes done to carry an oil channel from one point to another through the body of a casting, thus making it possible, for example, to feed two bearings from a single oil supply without external piping. Elbows with square inside corners are readily die-cast or cold-chamber pressure cast without knockouts, but elbows with an inside fillet require a knockout unless the core can be rocked into place by moving it through a circular arc.

Gears—

Any type of gear with a tooth form which will clear a die can be die-cast or cold-chamber pressure-cast and numerous gears made in these ways are employed in industrial products. Although the majority of these gears are for light mechanisms, some for quite heavy service have been made. For light lathe applications, with gears running dry, greater wear resistance has been attained with die-cast zinc-alloy spur gears than with gray cast-iron machined gears; and the cast tooth is of course as accurate in form as the die itself, and in general is used without machining.

Die-cast and cold-chamber pressure-cast spur and internal-gear teeth, in general, have to be given a slight draft, at least if the face width is considerable, hence the tooth elements are not exactly parallel unless a shaving or equivalent machining operation is performed. Some other forms of teeth, such as those for bevel gears are die-cast or cold-chamber pressure-cast with substantially perfect tooth form without machining. Internal gears are as easily die-cast or cold-chamber pressure-cast as those of the external or spur type and either may have teeth shrouded on one side with resultant strengthening, whereas cut gears of this type are difficult and expensive to machine. It is also an easy matter to die-cast or cold-chamber pressure-cast a square or splined hole in the hub or to split the hub for clamping to a shaft, whereas it would cost much more to obtain similar results by any other process.

Worms and worm wheels are readily cast by either the die or cold-chamber pressure methods, although for precision gears of this type, on which very smooth tooth surfaces are required, some machine work is necessary, and allowance for this must be made in the casting, as it must in any type of gear where such machining is to be done.

Surfaces—

In parts that are to be plated, deep, narrow, closely spaced ribs entrap buffing compound and are difficult to clean properly. Front faces absorb most

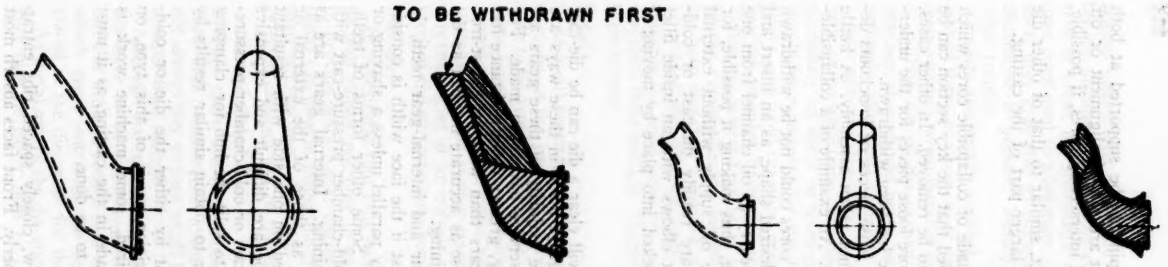


Fig. 4. Die-cast spouts for kettles, showing arrangement for removing crooked cores. *Left:* a three-cored spout; *right:* a two-cored spout

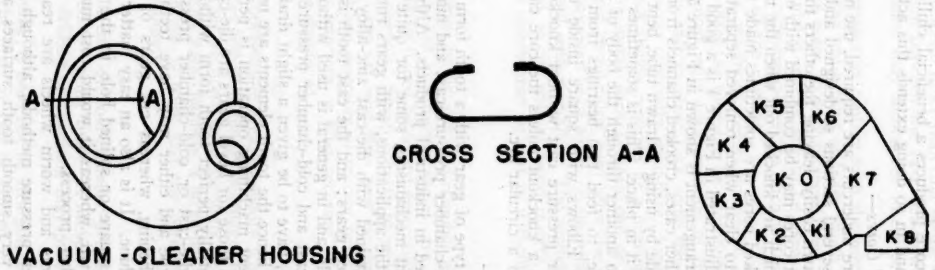
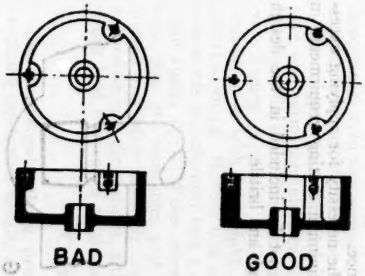


Fig. 5. Die-cast vacuum-cleaner housing, showing collapsible-core arrangement

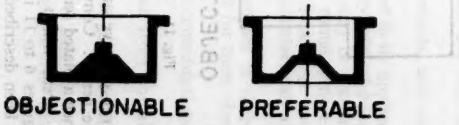
KO is the main core, and *K1* to *K7* are core pieces surrounding *KO*. After *KO* is withdrawn, *K1* is pulled toward the center, breaking the lock holding *K1* to *K7* in the casting so that cores *K2* to *K7* can be pulled out one after another.

(*Fig. 6*)

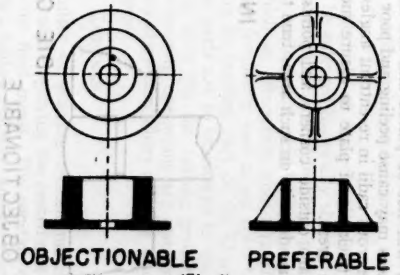


(*Fig. 7*)

Figs. 6 and 7. Illustrations of how undercuts in metal-mold castings can be eliminated by good design



(*Fig. 8*)



(*Fig. 9*)

Figs. 8 and 9. Objectional and preferable features of metal-mold castings, with respect to uniformity of section

of the plating current, making it difficult, if not impossible, to plate between the ribs. Failure to plate such areas results in contamination of the plating bath, which causes serious difficulty.

Recesses in which gas can be entrapped should also be eliminated. These areas will not be plated and the flow of excess gas over the surrounding surfaces may cause peeling and poor appearance.

Generous radii in re-entrant angles avoid the necessity for applying excessive thickness of plate to assure meeting minimum coating requirments in these areas.

Sharp outside corners and points should not be included in the design because deposits on such areas tend to be rough and brittle.

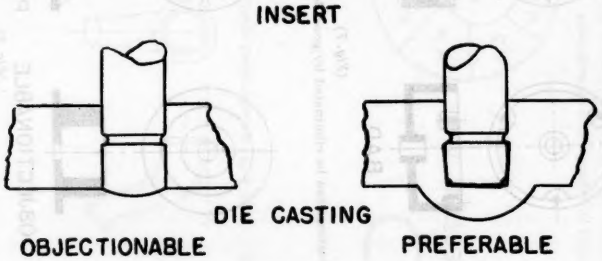


Fig. 10. Objectional and preferable methods of fastening the end of an insert in a metal-mold casting

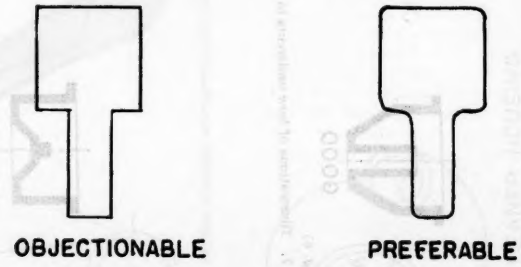


Fig. 11. Sharp corners are objectional and corners of large radii are preferable

Large concave areas are difficult to plate because of low current density at the center. Convex shapes are easier to plate than flat shapes.

Since a plated part must be buffed, a brilliant luster cannot be obtained in those areas which the buffing wheel cannot reach.

Figures 6 to 11 illustrate in simple form some of the design features that have been described.

Unless otherwise specified, die and cold-chamber pressure castings are supplied with a commercial surface finish—that is, the best obtainable in regular routine with modern machinery and with up-to-date and carefully

controlled metallurgical and casting practices. Such a finish is reasonably free from surface imperfections, such as pits, draws, run marks, scabs, etc.

Where a better finish is required, it must be requested of the die caster. Such a finish naturally costs more than the commercial finish.

When castings are used in locations where the surface appearance is of no importance, even the commercial finish would not be needed and a sub-commercial finish would save some cost.

The scope of metal-mold castings, particularly of die, cold-chamber pressure, and permanent-mold castings, can be enlarged materially through combination with other manufacturing processes, such as cold forming, punching, etc. Figure 12 shows a die-cast pull knob for a refrigerator vegetable drawer, cast with a straight skirt which is afterwards cold-formed into spherical shape. Hollow box sections are frequently cast as an open U and afterwards transformed into a closed box by bending part of the U over at right angles (□). When other separate parts are to be riveted to die castings, pins are sometimes cast integrally with the die casting proper, and riveted over after assembly. Such cold-forming operations are usually performed on zinc die castings, although new aluminum alloys are now available which lend themselves to the same process.

Centrifugal Castings.

The centrifugal casting process consists of pouring molten metal into revolving molds that usually are of metal and employing the centrifugal force induced to form, compress, and cleanse the fluid metal. The rotation of the mold distributes the molten metal to form a hollow cylinder, and the thickness of the wall is controlled by the amount of metal poured into the centrifugal mold. Cores are used only to produce irregularly shaped inside walls.

The whirling mass forced tightly against the mold is cleared of gases by compression. Slag inclusions, oxides, and other impurities, being lighter than the molten metal, are squeezed out of the revolving mass and float on the inside surface of the metal.

Centrifugal castings can also be made in refractory molds, and compete with centrifugal castings made in metal molds.

The most common form of centrifugal castings is limited in its applicability to ring- or tube-shape castings with a hollow, straight, cylindrical bore concentric with the outside. Irregularly shaped inside bores may be produced by the use of refractory cores. The outside surface may be round, square, hexagonal, octagonal, etc., and with or without circular flanges or grooves. Occasional bosses, etc. breaking the symmetry of the perimeter, can also be cast, provided they are not too high or too thin.

Castings without a hole through the center, when compact in shape and relatively small, may be produced by making arrangement for them along the perimeter of a circle concentric with the axis of rotation.

Practically all of the common metals can be cast by the centrifugal method.

The advantages of this method of casting are:

(a). Dense structure of castings produced, and freedom from porosity.

(b). Low mold cost.

(c). Practically no limitation to the size of castings that can be made, provided they have a through center hole.

(d). Castings with a through center hole can be made in long pieces, from which required lengths can be cut off in the same manner as with extruded metal.

The limitations of the method are:

(a). Castings located concentric to the axis of rotation of the mold must have a through center hole, and considerable extra metal must be provided for machining on the inside wall of this hole.

(b). The peripheral outline must be reasonably symmetrical.

(c). Close tolerances and sharp outlines are obtainable only at the periphery. In castings located eccentric to the axis of rotation of the mold, the outlines near the center of rotation will not be so sharp as those at the outer circle.

PART II:

HEADING AND UPSETTING; SCREW-MACHINE PARTS; PRESSING AND DROP FORGING; EXTRUSION; AND RESISTANCE WELDING.

Cold heading is a gathering-up operation as differentiated from drop forging, which is essentially a flattening or spreading operation. The stock is upset by pressure on the end, forcing it out in all directions but with the upset confined in heading tools or in impressions in the gripping dies. The upset may be either at one end or sometimes between the ends. Upsetting works the metal equally as well as a drop hammer, if not better.

Cold heading, or upsetting, is the least costly method of fabrication where large production is required and the shape lends itself to the process. Close tolerances (of the order of ± 0.002 inch per inch), high speed of production, and low cost are the characteristics of this method of production.

Any metal which is reasonably malleable and does not work-harden excessively may be cold upset, including plain or alloy steels of low or medium carbon content, copper, many of the copper alloys, Monel, and aluminum and its modern wrought alloys.

Cold upsetting utilizes the raw material most economically and minimizes the amount of scrap.

A great variety of shapes can be made by this process. The limitations lie primarily in the ratio of the volume of the displaced material to the diameter of the stock. Greater displacement is possible in multiblow upsetters with intermediate anneal.

By reversing the process, the stock can be extruded to a smaller diameter at one end.

The dies for cold upsetting cost less than drop-forging dies, both in first cost and in upkeep. The die setup for cold heading is also less.

Internal strains are likely to be created in the upset section. These should be relieved by a strain-relief anneal if when in service the part is subjected to severe stresses, particularly impact or fatigue.

Upsetting machines are practically automatic, and one operator can operate a battery of them. Upsetting operations should not be considered for small production.

Particular attention is called to the possibilities of using upsetting machines in combination with screw-machine or punch-press operations; for example, to the possibility of putting the stock through a header to upset certain sections, and then feeding through a screw machine for finishing, drilling, etc.

For parts where the deformation of the stock is greater than can be obtained by cold upsetting, as for large bowls, crankshafts for refrigerators, etc., the parts may be hot headed or bulldozed. The accuracy, in general, is about the same as that of drop forging, and fairly complicated or irregular shapes can be produced.

A variation of hot upsetting or bulldozing is the electric upset which consists of using suitable rod material, either ferrous or nonferrous, clamping the jaws of a butt or flash welder around the section to be upset, heating the section from the welder, and forcing the jaws the requisite amount. This gives a uniform upset between the clamps. The upset parts can then be fed through a screw machine and finished to the necessary dimensions or subjected to any other auxiliary operation required to give the desired shape.

Screw-Machine Parts.

The use of screw machines is particularly attractive where rotary machining operations, such as turning, threading, forming, facing, or drilling, are repeated over and over again on parts made in large quantities.

The finished cost of screw-machine parts is mainly determined by the equipment and setup; that is, whether the parts are made on a hand machine or on an automatic machine, whether the tools operate one at a time or several operations are performed at once. The modern automatic screw machine has high production speed, and several machines can be handled by one operator. On the other hand, it is less accurate than hand machines (although tolerances of the order of 0.0002 inch per inch can be obtained by subsequent centerless grinding). It also requires a longer setup time, higher tool costs, and is limited to the use of bar stock and tubing, except where hopper and magazine feed are installed for the handling of individually preformed parts such as upset or forged pieces, whereas the hand screw machine can handle odd shapes in short sections.

The quantity to be produced has to be balanced against the time of production and the cost of the setup. It is therefore advisable to bunch orders for screw-machine parts in order that automatic machines can be used for their efficient production. In many cases this fact is overlooked and small orders are placed at frequent intervals for the same parts, instead of large orders reasonably spaced. The small orders require hand machining with high cost.

In general, the waste of material in manufacturing parts by a screw machine is greater than that by any other method. However, from the cost standpoint, there are many parts that can be fabricated in the screw machine more economically than by any other method.

Several of the methods of fabrication described in this article are preferable to screw-machine operations in many cases, particularly when conservation of material is important. For instance, products produced by upsetting, or die castings made on special small machines or in unit dies, should be balanced against screw-machine parts. Consideration should also be given to the possible use of extruded sections or parts as preformed materials for screw-machine work.

Practically any metal that is machineable can be fabricated in the screw machine, but for automatic work the machining qualities of the material should be given especial consideration. Free-cutting brass is at the present time the easiest material for screw-machine work, with the free-cutting aluminum of the 11ST variety a close second. Free-machining Bessemer screw stock ranks third. During the past few years, manufacturers have also brought out free-machining varieties of stainless steel, Monel, silicon bronze, phosphor bronze, and pure copper.

In many instances where the machining operations are manifold, a free-machining material of inherently higher material cost will work out more economically than harder-machining material which originally costs less. Aluminum and brass screw-machine products are frequently of lower cost than the same parts made from free-machining steel.

Pressing and Drop Forging.

Hot pressing, which is now applied to ferrous as well as to nonferrous materials (copper, brass, bronze, aluminum, Monel, etc.), is a variety of the better-known drop-forging process in that a sustained pressure, instead of a sudden blow, is applied to the block to be deformed. Hot-pressed parts usually start with a partially preformed section made by extrusion, or by some other method, and inserted in the die block for final deformation under the press while red hot.

This double working of the material, in the preliminary extrusion and the final hot pressing, results in an extremely dense and close-knit structure which is especially well suited for applications where highest possible strength and reliability are required.

The accuracy of hot-pressed parts is ordinarily of the order of ±10 to 15 mils on all dimensions, but a new die will turn out work that is more accurate. This is somewhat better than the accuracy that can be expected in drop forgings.

The main differences between the hot-pressing and the drop-forging processes are as follows:

(1). The rate of production is usually higher for drop forgings than for hot-pressed parts.

(2). In the hot-pressing process, complicated shapes can be formed at one heat where it may be necessary to have several dies and several heats to do the same work by the drop-forging method.

(3). Hot-pressed parts can be made more accurate, require less draft, and have fewer design limitations than drop forgings.

(4). Dies for hot pressing cost less than those for drop forging.

Therefore, for such shapes as can be handled in one heat, where production is high enough to justify the forging-die cost, and where the accuracy and tolerances of drop forging are satisfactory, drop forgings will cost less than hot-pressed parts. In other cases, hot-pressed parts will be more economical.

It should be remembered, however, that production difficulties with drop forgings (particularly as to the number of dies and heats required) can be foretold only by an expert study of each individual case.

Cold pressing is frequently applied to parts of reasonably simple shape, especially in nonferrous materials. This method is more economical than hot pressing and offers greater production rate, lower equipment charge, lower maintenance cost of dies, somewhat closer tolerances, usually better machinability, and lower cleaning cost. However, the hot pressing process is more versatile than cold pressing.

In competition with metal-mold castings, hot-pressed or drop-forged parts offer (generally at a slightly higher cost) greater strength, assured dense and solid structure, and wider range in strength and other properties. High-strength steels, and high-melting-point metals like pure copper, Monel, etc., cannot be handled in metal molds.

Extrusion.

Extrusion makes possible the economical manufacture of sections which do not change their circumferential contour throughout their whole length. Long stock bars are produced (length depending on cross section and size of original billet) and cut to length as required for the part. Frequently, extruded bars are put through subsequent screw-machine operations where local changes in perimeter are wanted.

In the extrusion process, billets of nonferrous materials of the hot-working variety are heated and, while in plastic state, are forced under high pressure through a steel die and over a steel mandrel. The process differs from drawing, in which metal is pulled cold through a die as opposed to pushing it through hot by extrusion.

Close tolerances are obtained on solid extruded sections (of the order of ±5 mils thickness and width for sections up to ½ inch and about ±10 mils for sections over 1 inch to 2 inches, for the cuprous metals. The tolerances for aluminum and magnesium are somewhat greater.

These tolerances can be materially improved by a subsequent cold-drawing process. Cold drawing after hot extrusion is also used to straighten long bars, to thin down heavier sections, and sometimes to draw together sections

that have been extruded open, so that they have an almost imperceptible gap. Open sections can be extruded with interlocking seams or other suitable shapes, which when drawn together form a tight joint.

Extrusion dies for ordinary shapes are quite inexpensive, and therefore extrusion becomes economical for even relatively small production. Manufacturers of extruded materials have thousands of dies in stock and frequently a suitable shape can be chosen from a stock list of available sections.

Figure 13 illustrates the extrusion principle. Considerable improvement in extrusion has been made during the past few years, and hollow sections of quite complicated form are now produced with excellent accuracy of inside and outside dimensions and wall thickness.

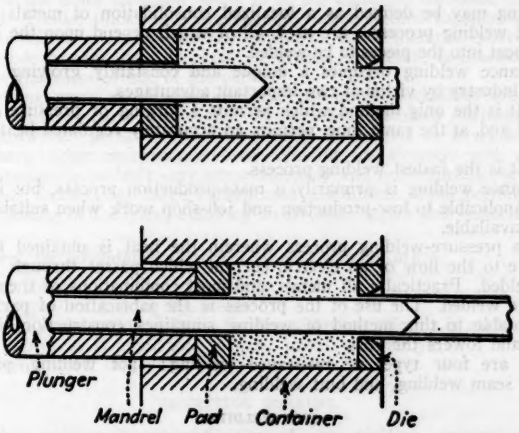


Fig. 13. The principle of tube extrusion

(*Above*). The mandrel is advancing and forming the bore of the tube. (*Below*). The plunger is advancing and forming the tubing over the mandrel.

A variation of the extrusion process of relatively recent origin is the so-called impact extrusion process whereby circular, oval, rectangular, plain, or corrugated can- or shell-shaped parts of practically unlimited length can be made with thin walls and thick bottoms, while bosses, lugs, rivets, stems, or necks can be made integral with the closed end, either inside, outside, or on both sides of the end.

The commercial advantage of impact extrusion may be readily appreciated from the following consideration.

While relatively shallow shells or cans of uniform metal thickness throughout can usually be made most economically by pressing or drawing, the number of operations required to draw the part to the desired depth when the depth-to-diameter ratio exceeds about 1½ to 1 greatly increases the cost and makes impact-extruded products competitive. Another problem arises when it is necessary to have bosses, lugs, rivets, or necks on the closed end of the shell, or when the bottom must be considerably thicker than the walls. Such designs would be, in most instances, impossible to make as a one-piece stamping, but they can now be made quite inexpensively by impact extrusion.

In impact extrusion, a cold or moderately heated disk or slug whose volume roughly corresponds to the volume of metal in the finished part is pressed in a shallow cup-shaped die in the power press. The punch, the diameter of which is smaller than that of the die, then strikes the slug. This forces the ductile metal of the slug to flow through the annular clearance between the punch and the die and upward around the punch. The shapes which can be obtained directly by impact extrusion can be further developed by subsequent forming, stamping, or spinning operations.

Impact extrusion is applied primarily to aluminum, magnesium, and zinc alloys at the present time.

Resistance Welding.

Welding may be defined as a localized consolidation of metals. Several different welding processes are used, all of which depend upon the introduction of heat into the pieces to be welded.

Resistance welding occupies a unique and constantly growing place in modern industry by virtue of two important advantages.

(1). It is the only method which permits a forging or pressure action at the weld and, at the same time, permits an accurately regulated heat application.

(2). It is the fastest welding process.

Resistance welding is primarily a mass-production process, but it is also readily applicable to low-production and job-shop work when suitable equipment is available.

It is a pressure-welding process wherein the heat is obtained from the resistance to the flow of an electric current which passes through the area to be welded. Practically all metals, and most combinations of them can be resistance welded. The use of the process in the fabrication of parts which are adaptable to this method of welding simplifies construction, improves quality, and lowers the cost.

There are four types of resistance welding: spot welding, projection welding, seam welding, and butt welding.

Spot Welding.

Spot welding is commonly applied to sheet-metal and formed parts. The heat and pressure are confined to a relatively small portion of the area of the parts being joined, by the use of electrodes having small areas of contact. The parts to be welded are placed in position between the electrodes and, while the full required pressure is being applied, the electric current is allowed to flow just long enough to bring the spot to welding temperature. It is evident that, for reliable results, the parts must be clean and fit properly. With this short time of heating and quick cooling, there is little or no discoloration of the material.

The initial assembly of certain refrigerator evaporators utilizes spot welds to hold two sheets together. These spot welders are standard machines and operate to produce 140 welds per minute per machine with the current flowing 1/30 sec per weld. Welds in thicker material, requiring longer applications of current, must be made at correspondingly lower speeds with standard equipment. However, in cases where the amount of production justifies the cost, special equipment can be procured with multiple electrodes, combined with an assembly fixture. There are many modifications which can be built into special machines to speed up operation and make them largely automatic. Spot welds along lines may often be made faster in a standard seam welder by using rolls and an increased "off" time between impulses of power.

Practically all combinations of the ductile metals and alloys can be spot welded. However, some, like copper to aluminum, and aluminum to magne-

sium, form alloys of practically no strength. Others, such as zinc and some of the high-chromium alloys, result in grain growth during the shortest possible welding time. Zinc-alloy die-casting alloys can be welded with little loss of strength, but with reduced ductility. Free-turning screw-machine stock with high sulphur and high phosphorous content frequently refuses to weld, or results in brittle welds, and hence should be avoided. In most cases, however, with clean, properly prepared metal parts the strength of spot welds is perfectly satisfactory. Copper and silver, with their high heat conductivity, have no appreciable resistance for the generation of heat, but these metals can nevertheless be welded by the use of special techniques.

Two one-inch thicknesses of steel or two $\frac{1}{2}$-inch thicknesses of yellow brass are probably the maximum that have been satisfactorily spot welded. The limit in the other direction seems to be the minimum thickness that can be handled. Unlike thicknesses are regularly spot welded together and, in general, the thinner piece governs the technique. Sheet material is frequently spot welded to heavier bars, brackets, or fittings, and there is practically no limit to the thickness of one of the parts.

Spot-welding guns, usually semiportable and quite specialized, are sometimes used on large parts that cannot be carried to standard stationary spot welders. However, portable guns have many limitations as to adaptability and also have higher maintenance costs. Welding transformers with welding guns can frequently be built very advantageously and economically right onto the assembly fixtures for large complicated assemblies. This permits more exact positioning of the guns, resulting in stronger welds and better appearance.

In general, the advantages derived from spot welding are:

(1). The simplicity of the preparatory work.
(2). The speed of making the welds.
(3). Usually, the weld needs no further attention after it is made.
(4). The process is applicable to most metals and alloys.
(5). Discoloration and distortion are minimized.

PROJECTION WELDING.

Projection welding is a modification of spot welding, accomplished by preparing the pieces to be welded with embossed, machined, or coined projections or contact areas, to concentrate the pressure and heat for welding at these points while using flat electrodes in the welding machine. This method has the following several advantages when the parts can be suitably prepared for it:

(1). Even for a single weld between parts, the welding conditions are more easily controlled by the use of a projection. The location of the weld, its area, and the surface contact conditions are more certain than when using regular spot welding.

(2). Flat or formed electrodes are used, contacting the parts over considerable areas. This results in easier electrode maintenance and more accurate alignment of parts.

(3). By using several projections within the area of the electrodes, several spot welds may be made simultaneously, thus saving handling time.

(4). Studs with domed ends are easily assembled to plates. Headed pins can be welded through holes in levers, leaving the lever free to move after fastening, or nonmetallic parts can be fastened onto metal by this means.

To date, there has been no hard-and-fast rule laid down for the design of the projections, but a few general rules have been developed. Sheet material is usually prepared by embossing round protuberances, whose height equals

from 10 to 90 per cent of the thickness of the sheet, and whose diameters are between one and two times the thickness of the sheet. The low projections often give satisfactory strength with minimum marking or distortion, while the higher ones give greater strength.

Annular, or ring, projections are often used on screw-machine parts and around holes and give pressure-tight welds in sizes up to the capacity of the welding equipment available. Rings two inches in diameter have been welded so that they held 2500 pounds per square inch pressure. When parts must fit tight against the surface, recesses may be left around the projections to provide for extruded metal.

Studs, either plain or threaded, are usually prepared with a spherical dome, using about a 1½-inch radius on the end to be welded. An appreciable percentage of the cross section may be welded with negligible deformation or extruded metal, but if the entire area must be welded, some cleaning may be required.

Crossed wires, as used in most types of wire goods, provide ideal projection-welding conditions, and frequently similar conditions can be provided in the forming of parts to be welded.

The side of a round rod will usually weld readily in short lengths to a flat surface. Clevises are produced this way on the end of rods by welding flat-plate punchings simultaneously to the two sides of the rod.

One of the most famous projection-welded products was the Ford wire wheel which was produced for several years. Millions of spokes were projection-welded at both ends, to the rim and hub. These spokes did not pass through either rim or hub. In certain refrigerators, dozens of parts are projection welded to the compressor case, evaporator, and condenser. In fact, the completed refrigerator assembly, as well as many of the subassemblies, is supported entirely by projection welds. The same applies to certain distribution transformer tanks, to which all the brackets, lifting hooks, and other small parts are now projection welded. The annular type of projection is used for the seal weld in metal radio tubes, and to attach parts to larger vacuum tubes.

Projection welding can be used for nearly all the metal combinations that can be spot welded.

Projection welds vary in size from the ball tips welded onto fountain pen nibs to the projection welds one inch in diameter that one automobile manufacturer uses to hold brake drums onto wheels.

SEAM WELDING.

Seam welding is a resistance-welding process wherein overlapping or tangent spot welds are made progressively. This is most often done between wheels or roller electrodes, but frequently the parts are assembled on a bar or platen while a roller or wheel passes over the other surface. At times, seam welds are also produced slowly in regular spot welders.

One rule which applies to spot as well as to seam welding is that the stock should be so wide that the weld does not come all the way to the edge. If the weld does come to the edge, the metal softened in welding is squeezed out, the electrodes or parts skid, and a weak weld with poor appearance results. If desired, the extra flange width may be trimmed off after welding, but there should be cold metal on all sides of the weld to confine the softened area during the welding process. Seam welding is used on many types of tanks for oil switches, capacitors, transformers, automobiles, and airplanes.

Steel plates ⅜ inch thick have been seam welded together to hold a pressure of 3000 pounds per square inch. But, to date, probably half that thickness is the maximum that has been seam welded on a production basis.

However, like spot welding, a thin sheet can be seam welded to another part of almost unlimited thickness.

The possibilities for seam welding do not include all the combinations of metals that can be spot welded, but the field is large. The following production jobs illustrate the reliability of seam welds but, to avoid pin holes and small leaks, the parts must be clean.

The refrigerator evaporators and condensers previously referred to are assembled almost entirely by seam welding. The gastight seam around the edge of the evaporator is made at the rate of 72 inches per minute, while the intermittent seams between the louvers are welded at the rate of 17 feet per minute. The stock used is 18-8 stainless steel 0.025 inch thick, and the intermittent seam with nine spot welds in two inches furnishes sufficient strength with least distortion. Thus "spot welds" are made at the rate of over 900 per minute per wheel, which shows how a standard seam welder can beat a standard spot welder at its job. The condenser is made of 0.037-inch mild-steel sheets and is seam welded at the rate of 10 feet per minute. All these seams are pressure tight.

Every evaporator and condenser has to pass a pressure test of 200 pounds per square inch, yet the rejects due to welding amount to only a fraction of one per cent.

Each of the distribution transformer tanks referred to is made of 3/32-inch sheet steel and has four oiltight seam welds. The bottom is cupped, inserted with the edges down, and seam welded around the bottom; then the three "pockets" where the leads are brought out are seam welded on oiltight. This welding is done at 40 inches per minute.

Another design which may be mentioned is illustrated by the liquid receiver used on some refrigerators and by one type of capacitor-motor case. The top and bottom halves are identical drawn parts with flanged edges. After assembling, the two flanges are seam welded together.

BUTT WELDING.

In butt welding, fusion is produced over the entire cross-sectional area by either of the following means:

Flash Butt Welding: Potential is applied before the parts are brought in contact, and heat is derived principally from a series of arcs between the parts being welded.

Upset Butt Welding: The potential is applied after the parts to be welded are brought in contact, and heat is derived principally from resistance. In either flash or upset butt welding, the weld is finished with high pressure, creating a forged structure of high quality.

Different techniques are used in butt welding, depending on the material and the size or design of the parts. The two parts to be welded are usually clamped in jaws in such a way that the ends or edges, as the case may be, come into proper alignment. The jaws must contact enough area to hold the parts true, and to introduce high current into the parts uniformly without creating hot spots. After the temperature of the joints is raised to the desired degree, the parts are pushed together with high pressure, creating a forged condition at the weld.

Ferrous materials are usually flash welded, for three reasons. The joining surfaces need no particular preparation, and are "burned" to a fit. Less power is consumed because the arcing creates more heat with a given current. Since the surfaces are burned away, the weld is made on clean virgin metal. The surfaces that contact the electrodes should be reasonably clean to pick up the large current without burning.

Certain sizes of enclosing cases, which are made of 0.044-inch steel, but not in sufficient quantities to pay for drawing dies, are fabricated. The sides

are formed of one sheet, bent to shape, and flash welded at the joint, then the bottom is spot welded to an internal flange. The finished weld is practically invisible.

The longitudinal seams in distribution transformer tanks have been flash welded for years with very good results. Flash welding is also used for welding shanks of mild steel to tools of high-speed steel, such as drills, reamers, etc.

Another form of flash butt welding, known as "percussion welding," using the direct discharge from capacitors to supply the heat, is utilized in the lamp industry to fabricate lamp leads. Automatic machinery takes copper, Dumet, and nickel wire from three spools, cuts pieces to length, and butt welds them together at the rate of 200 per minute. Flash welds are made in sections varying from 0.010-inch diameter wire to 60 square inches. The size is limited only by the equipment and power available.

Upset butt welding is used principally on non-ferrous materials, for welding wire, bars, tubing, formed parts, etc. Materials with short plastic ranges, like copper and aluminum, usually weld best with continuously applied pressure to prevent slumping and to avoid irregular burning. Upset butt welding is being used in making continuous lengths of bull wire for drawing; in making copper end-rings for induction motors; and in making aluminum-wire gaskets for metal-tanks mercury-arc rectifiers.

The upset butt welding of aluminum to copper is unusual in that a double pressure cycle is used, and it serves to illustrate the versatility of the process. A light pressure with high resistance at the joint is used to generate the heat, then a very heavy pressure is applied to squeeze out the brittle eutectic alloy. Automatically controlled power-driven equipment is used when it is desired to duplicate results consistently at a rapid rate.

Resistance welding in its various forms offers opportunity for marked economies in the production of metallic parts having good strength, appearance, and reliability if proper consideration is given to all factors involved in the job and the best methods and techniques are employed.

Part III.

Stampings, Formed and Drawn Parts, Soldering and Brazing, Powder Metallurgy.

In designing parts for fabrication, particularly where large quantities are involved, the importance of stamping from sheet metal cannot be overestimated. This process offers a means of large-quantity production that is economical and accurate, and that permits exact duplication.

STAMPINGS.

Punch-press operations can be performed on many different types and shapes of parts, and may involve shearing, blanking, shaving, trimming, lancing, piercing, broaching, forming, drawing, swaging, coining, embossing, burnishing, seaming, crimping, or almost any combination of these functions, to provide parts at comparatively low labor cost.

The factor of quantity is inseparable from tool cost. There are usually several methods of producing the same parts, using punches and dies varying in initial cost and cost of piece production. The method selected should be the one which, all factors considered, will result in the lowest ultimate cost of the parts. This cost is the cost of producing a given quantity of pieces, plus the cost of the necessary tools. Full consideration of ultimate cost will avoid either undertooling or overtooling. Either condition can prevent true economy.

Proper regard given to the factors of part design and total quantity will assure correct tooling and lowest manufacturing cost. It is impossible to correct tooling or manufacturing procedure after production has actually been started without wasting money in the form of tool revision or method changes.

Flexibility—

The flexibility of punches and dies is apparent in the variety of operations which can be performed. It is also apparent in the wide variety of materials which can be worked. In these respects, punches and dies have greater flexibility than other low-cost production methods.

Durability—

The control of accuracy in punch-die operations is simple in comparison with most other manufacturing methods. The wear on the tools is slow when measured in number of pieces produced, a factor which also contributes largely to control of quality.

Tolerances—

Tolerances which can be maintained in production are affected by so many elements that it is extremely difficult to give any set of rules or allowances. The kind and thickness of material used; the size of the part; the dimensions and amount of reduction between draws; number of holes or slots and their relation to bends, periphery, and other holes all affect the tolerances which can be maintained in blanking, piercing, and forming. However, the tolerance figures in Table III will be of assistance to designers.

TABLE III

BLANKING AND PIERCING TOLERANCES

Thickness of Material in Inches	MAXIMUM TOLERANCES IN INCHES		
	Up to 3 in. Wide	Up to 8 in. Wide	Up to 24 in. Wide
0.025	+0.003	+0.005	+0.008
0.030	+0.003	+0.006	+0.010
0.060	+0.004	+0.008	+0.012
0.084	+0.005	+0.009	+0.014
0.125	+0.006	+0.010	+0.016
0.187	+0.010	+0.016	+0.025
0.250	+0.015	+0.020	+0.035

It should be noted that these tolerances are all given on the plus side. The plus side refers particularly to blanking. The size of the blank die determines the size of the blank produced; and as grinding is done to resharpen the die, the die becomes larger, due to clearance angle on the sides, thus causing the blank to increase in size. For tolerances on pierced holes, the figures should be used as minus tolerances. The diameter of a hole in a blank is determined by the diameter of the piercing punch, and since the punch wears with use, the hole pierced will become smaller and the tolerances should be on the minus side. Of course the hole in the die for the pierce punch also becomes larger with wear, but this only increases the

clearance between the punch and die, and results in an increased burr. This does not increase the dimension of the pierced hole in the blank.

These are tolerances that can ordinarily be maintained with steel, brass, copper, or aluminum. Generally speaking, the softer materials, such as fiber, rubber, etc., cannot be held so close. In order to maintain closer tolerances with them, a compound die is used, or for thicker metallic materials, resort is made to "shaving." The use of a compound die will usually increase the tool cost, and the addition of a shaving operation will increase the manufacturing cost of a punching.

Limitation of Punches and Dies--

The principal limitation to the use of punches and dies is that the quantity of parts required will not always justify the cost of tooling. (Except for certain simple parts, the die cost of metal-mold casting is generally lower than that for a stamping.) Rapid strides have been made in the last few years in reducing the manufacturing quantity at which punch and die operations become economical. This has been achieved partly by refinement in the *design of stampings,* but to a larger extent by a radical change in punch and die construction to meet low-quantity manufacturing.

The ultimate quantity of parts required determines to a large extent the production method and type of die selected. Where ultimate-parts quantity is high, say over 100,000, a first-class long-life multiple-operation die is indicated, which will probably be automatic and will result in lower labor cost. As the quantity decreases, the tools can be simplified, which will reduce tool cost, but increase operation cost.

There are various types of tools which can be built to produce the ultimate quantity required at the most economical tool and operation cost. Therefore, it is essential for the designing engineer to analyze carefully the possible ultimate parts quantities and so instruct the planner, in order that the most economical production method can be selected.

Design of Stampings—

In design of parts to be produced with press tools, it is often possible to reduce considerably the cost of tools, the cost of producing the stampings, or both, by a knowledge of the various points which affect tool design, labor, cost of operations, or material utilization. Sometimes it may be possible to avoid the use of costly tools by making a punching in two or more pieces which can be welded or brazed together.

Material—

The material of which a stamping is made is an important factor in its cost. In general, material accounts for approximately 70 per cent of the factory cost of stampings; therefore, the designer should select the least expensive grade of material which will do the job. For piercing and blanking operations, most grades of material will punch satisfactorily, except that scaly material tends to shorten die life and increase die grinding costs where a large quantity of punchings is produced.

Where forming operations are involved, it is often desirable to use a strip material, since greater thickness variations are experienced in sheet material and these may destroy the uniformity of the bending angle.

This same condition often occurs in shell drawing. Too great a variation in material thickness will cause a variation in height of drawn shells and will sometimes cause excessive breakage. Material for shells should be of drawing quality. If the height of draw is approximately 40 per cent of the shell diameter, or greater, a deep-drawing grade of material should be selected.

Material for stampings involving swaged portions should be of drawing quality. It is often necessary to spot anneal (anneal a small portion of the

blank adjacent to the hole) to swage to the required height without cracking.

Where large quantities of parts are required, they are processed in automatic presses with roll feed. Here it is generally desirable to have strip stock in coils to reduce operating labor. This applies to all materials 0.044 inches thick or less. In many press shops, roll straighteners are available to straighten material before it is run through the feed rolls at the press. In this case, material even heavier than 0.044 inch should be purchased in coils.

Steel is generally the cheapest kind of material. Stainless steel is hard to process and is comparatively expensive, but its use may reduce over-all cost by obviating a protective finish. Brass, aluminum, and copper can be used to advantage for the same reason. The use of copper-hardened zinc should be considered instead of brass in many cases where the full strength or temperature resistance of brass is not required. It may be blanked, formed, or drawn easily, it is nonrusting, and its cost per cubic inch is approximately one half that of brass.

Material utilization should be studied carefully when designing punched parts. Often slight changes can be made in design of parts which will considerably lessen the quantity of waste material. If the quantity of parts required is fairly large, it is desirable to consider the use of ribbed construction to reduce material thickness, the swaging of holes to obtain necessary thickness for threading, and other methods for reducing material costs.

Design of Blank Contours and Corners—

Blank shapes should be designed with true radii. Rounded corners are preferable to square corners as it is generally possible to produce round corners on a blank more readily and cheaply than square corners. The rounded corner can be completely machined in the die by a suitable automatic machine without subsequent filing or slotting. Such a machine performs milling and profiling operations by use of a template as a guide.

The statement that corners should be rounded holds true only for medium-sized punchings that must be blanked—that is, cut all around their periphery. In rectangular pieces which are merely cut to length, it is possible to make a piece and cut-off die, producing perfectly square corners, with no scrap material on sides or ends.

Also, if a punching is quite large or is for extremely high production, say one million or more, it is often desirable to make the die member in sections, to prevent warpage and loss in hardening, and also to allow slight readjustments of the blank opening, to compensate for wear. In this case, square corners would of course be preferable.

Design of Projections—

The width of any projection or slot in a punching should be at least 1½ times the thickness of the material, for metal that is 1/16 inch or more thick. For lighter gages than 1/16 inch, the narrow sections should not be less than 1/32 inch for economical tool manufacture and maintenance. Projections should be as short as possible, since the longer and narrower they are the more tendency there is for breakage in hardening, and consequent excessive tool cost.

Sometimes smooth edges and close tolerances are necessary only in part of a blank. If so, this should be specified, since it is often possible to incorporate a shaving operation on a progressive die, thus eliminating the extra operation.

Piercing—

When designing punched parts, care used in deciding the location, shape, size, and dimensions of pierced holes, slots, etc., will greatly reduce tool cost. The following are among the points that should be kept in mind:

Round holes should be used, wherever possible, in preference to slots or irregularly shaped holes since the original tool cost and tool maintenance will then be less.

The diameter or least dimension of any hole should not be less than the material thickness and not less than 0.030 inch in any case. It is possible to punch holes of smaller dimensions than the material thickness, but this always means increased tool cost and maintenance, plus the consequent delay in production caused by tool repairs.

The distance from the edge of a hole to the edge of the nearest other hole, or edge of the blank, should be at least equal to the thickness of the material, and greater wherever possible. Otherwise. it is difficult to prevent distortion of the hole or edge of the blank. Tool cost is increased by the necessity of providing inserts in the die (separate pieces dovetailed into the die block to prevent possibility of cracking in hardening), or special bushings containing groups of holes.

The location of holes with respect to bends in the blank is important. Holes should be located as far as possible from bends. Location of a hole close to a bend will cause distortion of the hole, as the bending action of the material elongates the hole if pierced and bent in a progressive die. To get a round hole, it is often necessary to add an extra operation to pierce the hole last. Close tolerance between holes should be avoided, as this increases tool cost. It may often be possible to use large holes to assure proper location of parts in assembly, thereby increasing the allowable tolerance of the center distances and diameters of holes.

Stock Dies—

For low production, it is often advantageous to use stock or standard dies. Stock dies may be defined as dies of standard sizes, cataloged and kept in stock for producing parts with little or no tool cost. These dies may be grouped in various combinations so that stampings can be produced of almost any size or shape.

The possibility of using stock dies for pierced holes should be kept in mind, especially when making comparatively small quantities of parts.

FORMING.

Forming dies take a variety of shapes and are often used in combination with piercing, cutoff, swaging, and other operations. Where parts are pierced, formed, and cut off in the same die, it is often very difficult to maintain a right angle at the bend, especially in the harder materials, owing to the springback of the material. Therefore, the designer should, where possible, allow for a slight deviation from an exact 90 degrees. This is especially true with heavy material, for instance 0.094 inch thick. If an exact 90 degrees is required, it may be necessary to build a more complicated die, thus adding to the tool cost, or an operation may have to be added, thus increasing the manufacturing cost.

Wherever possible, forming should be done at right angles, or nearly so, to the grain of the stock (that is, to the length of the strip used). Bends made parallel, or nearly so, to the grain of the material often cause fractures on the bending line. Where bends must be made at right angles to each other in the same punching, it is often desirable to have them occur at 45 degrees to the grain of the stock.

It is often desirable to have a hole in a piece being bent in order to prevent creeping of the material under the bending punch while the piece is being formed in the die. If such a hole cannot be tolerated, it is possible to prevent the creeping by adding spurs or sharp points in the form punch to engage the material being formed. However, the latter method will leave marks on the formed piece.

Dimensions for lengths of bent portions of a blank should be given as wide tolerances as possible, as it is quite difficult to hold close tolerances.

The height of short tabs and other formed portions of a blank should be at least 1½ times the material thickness, otherwise forming becomes exceedingly difficult.

Sharp radii in the thick materials should be avoided.

Also, the use of spring materials should be avoided where parts are to be formed. It is very difficult to get uniform bending in materials such as phosphor bronze, spring steel, etc. This is also true in a lesser degree of the harder grades of common materials, such as hard stamping steel and hard brass.

SHELL DRAWING.

In designing shells for production on a punch press, the following general comments may assist in obtaining the lowest tool and manufacturing cost consistent with design requirements.

Round shells always involve less tool cost, and generally less manufacturing cost, than shells of a rectangular or irregular shape.

Shells with flanges generally involve higher manufacturing cost and tool maintenance than shells without flanges. The latter are pushed straight through the die by the punch, whereas shells with flanges must be drawn in and pushed back out of the die. This slows up the drawing operation, and generally causes increased handling.

However, there are cases where a flange is to be desired, for instance, in rectangular or irregular drawn shapes. The trimming of this shell involves a trim die similar to a blank die, whereas if no flange were shown, it would be necessary to trim to height (involving considerable tool cost) or to draw with flange, trim, then redraw to remove flange, which would increase manufacturing cost. Sometimes when no flange is desired, it is possible to draw a part with a flange, then trim very close to the side, producing a narrow edge. If this condition is permissible, it should be indicated on the drawing. Also, if the sides of a drawn part are not too high (say 1/10 of the shell diameter), it may be possible to develop a blank which will draw up near enough to desired height to make trim unnecessary. In these cases, the tool department should be consulted as to what variations in height may be expected.

In drawing round shells, the maximum height that can be drawn in one operation is governed mainly by the diameter of the shell, the kind and thickness of material used, and the radius in the bottom of the shell and under the flange (if there is one).

Various lubricating compounds are used to facilitate drawing, prevent score marks, and reduce die wear. In order to obtain the required reduction in drawing, it is often necessary to anneal or copper-plate when using certain materials. When drawing steel, stainless steel, brass, and copper, annealing is often used to overcome the strain caused by drawing operations. Copper-plating is also being used extensively on steel shells before redrawing. The film of copper reduces die wear considerably, and seems to act as a lubricant to prevent score marks and facilitate the drawing action.

Where shells are to be drawn at, or anywhere near, the possible reduction percentages, radii in the bottom and under the flange should be as large as possible. It is rather difficult to confine this to a rule but, in medium-thickness material (1/16 to 1/8 inch thick), the radius should be at least six times the thickness of material. For thinner materials, this proportion should be increased, and for heavier it may be reduced. Shells with too small radii generally require extra operations, involving extra tool and

manufacturing cost. Radii in corners of rectangular shells should be as large as possible for the same reason.

The tolerances recommended for round shells made from materials of various thicknesses are listed in Table IV.

TABLE IV

RECOMMENDED TOLERANCES FOR ROUND SHELLS

Thickness of Material in Inches	TOLERANCE IN INCHES			
	Up to 2 in. Diameter		Up to 6 in. Diameter	
Up to 1/32	±0.005	(inside diameter)	±0.008	(inside diameter)
Up to 1/16	±0.006		±0.010	
Up to 1/32	±0.008		±0.012	
Up to 1/8	±0.010		±0.015	
Up to 1/4	±0.015		±0.020	

For rectangular or irregular shells, the tolerances should be approximately 20 per cent greater than those given in Table IV.

All of the drawing tolerances in the table are based on the first draw from a shell, the height of whose sides is from ½ to ¾ the diameter of the shell. If the sides are lower, it is possible to hold the shell to closer limits. Of course, closer limits can be maintained by "redrawing" or "sizing." This, however, usually entails increased tool and manufacturing cost.

GENERAL REMARKS.

The designing engineer should avail himself of all possible help in the preparation of drawings for stamped, formed, and drawn parts, and should freely consult with the planning department and toolroom heads in his plant, for guidance along the lines of economical design.

Often the equipment available dictates the trend in design, and many times a discussion between the designer or engineer and the factory personnel will bring about recommendations of changes on the part in question, and such changes, while retaining the limiting elements of design requirements, will greatly simplify fabrication of the part.

SOLDERING AND BRAZING.

Soldering and brazing offer low-cost methods of fabricating when suitable and properly applied.

DISTINCTION BETWEEN SOLDERING AND BRAZING.

Soft soldering is a method of joining metals by means of heat and a filler metal that has a melting point below 1000 F. Little alloying takes place between the filler metal and the metal being joined; and the strength of the joints depends on the effect of cohesion. The filler metal is referred to as solder.

Brazing is a method of joining metals by means of heat and a filler metal that has a melting point above 1000 F., but lower than the metal or alloys being joined. In a brazed joint, diffusion or alloying of the filler metal and metals being joined usually takes place. The filler metal is referred to as the brazing alloy. (Hard soldering and hard solders are no longer considered proper terminology.)

SOLDERING.

Solders—

Soft solders are made in many combinations from tin, lead, antimony, zinc, cadmium, bismuth, etc. Table V gives the properties of some of the more common soft solders.

Figure 14 shows the maximum long-time shear stress allowable at elevated temperatures. The maximum permissible shear stress decreases

TABLE V: SOFT SOLDERS

COMPOSITION, PER CENT				Softening Temp, C	Flow Temp, C	Remarks
Lead	Tin	Antimony	Silver			
90	10	..	..	295	310	Low cost, not so free-flowing
60	40	..	..	182	260	Most commonly used
37	63	..	..	182	182	Eutectic, high fluidity
...	100	..	..	232	232	Primarily for joints in electric conductors
...	95	5	..	232	240	High strength
97.5	..	..	2.5	305	305	High strength at elevated temperature. Sluggish

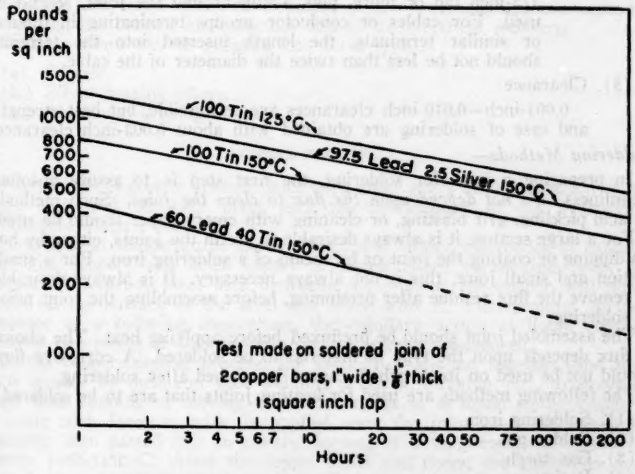


Fig. 14. Maximum shear strength of soldered copper joints, at elevated temperature

with time (stress and temperature being constant). Tin-antimony solder possesses high strength compared with other solders at room temperature, but is not reliable above 120 C., regardless of load.

These tests were made on two pieces of copper. If other materials, such as steel, had been used, the results might have been different.

Soft-solder Fluxes—

In making any soldered joint, a flux is necessary to obtain wetting between the solder and material being soldered. Both the solder and the material being soldered have inherently a thin film of oxide which retards wetting. The threefold action of a flux is as follows:

(1). It dissolves oxides already present in the material.
(2). It prevents further oxidation while the joint is being heated.
(3). It reduces the surface tension between the liquid solder and the material being soldered.

There are two general types of fluxes, corrosive and noncorrosive. The former are more vigorous in their action but are not permissible in certain applications.

Design of Soft-soldered Joints—

(1). Butt joints of any description should not be soft-soldered.
(2). Lap joints:
  (a). Mechanical:
    Area in shear should be calculated on the basis of shear strength as given in Figure 14.
  (b). Electrical:
    For strips 1/16 inch in thickness or less, a 1/2-inch lap or more should be used. For strips more than 1/16 inch thick, a 1/2-inch lap or more, plus a clip around the joint, should be used. For cables or conductor groups terminating in tubular or similar terminals, the length inserted into the terminal should not be less than twice the diameter of the cable.
(3). Clearance:
  0.001-inch—0.010-inch clearances are permissible, but best strength and ease of soldering are obtained with about 0.003-inch clearance.

Soldering Methods—

In preparing a joint for soldering, the first step is to assure absolute cleanliness. *Do not depend upon the flux to clean the joint.* Such methods as acid pickling, grit blasting, or cleaning with emery paper should be used.

For a large section, it is always desirable to pretin the joints, either by hot tin dipping or coating the joint or by means of a soldering iron. For a small section and small joint, this is not always necessary. It is always desirable to remove the flux residue after pretinning, before assembling the joint prior to soldering.

The assembled joint should be prefluxed before applying heat. The choice of flux depends upon the type of material to be soldered. A corrosive flux should not be used on joints which cannot be washed after soldering.

The following methods are used for heating joints that are to be soldered:

(1). Soldering iron.
(2). Solder pot.
(3). Gas torch.
(4). Resistance.

In the soldering-pot method, the metal in the pot, which is the solder or filler material, is heated somewhat above the upper melting point of the

solder. The joints are prefluxed and immersed just long enough in the bath to assure complete wetting.

The resistance method of heating has been finding wider use during the past few years due to the very rapid heating obtained by this method and, in addition, because it avoids the expensive and troublesome repairing of soldering-iron tips. (Copper soldering-iron tips under constant use have to be redressed at least once a day, and their total life is not particularly long, due to the constant dissolving of the copper by the molten tin.)

Figure 15 shows a set of electric resistance-soldering tools. The pencil type can be used where the assembly to be soldered can be grounded to one lead of the transformer. Contact is made at the joint with the carbon pencil, and sufficient heat will be generated to solder the joint. The fork type and plier type are used for joints where contact between the two carbon electrodes can be made by the joint to be soldered.

Soldering Aluminum—

It is physically possible to soft-solder aluminum, but, unless the joint is fully protected by means of paint or some other protective coating, the joint will disintegrate due to the galvanic corrosion between the aluminum and the solder. Spot welding or brazing of aluminum is always preferred.

To soft-solder it at all, the aluminum must first be "tinned" with a suitable solder. To "tin" aluminum, the surface must be vigorously rubbed with a soldering iron or wire brush through the surface layer of liquid solder to remove the oxide on the aluminum surface and to prevent its reforming while in contact with air. Once the surfaces have been tinned, they can be "sweated" together without any difficulty.

BRAZING.

Brazing, as a result of the development of new brazing alloys and methods of heating, has become an important tool in the electrical industry.

Brazing alloys can be grouped into three types:

(a). Copper.
(b.) Silver brazing alloys.
(c.) Aluminum brazing alloys.

COPPER BRAZING.

The process of copper brazing dates back many years but its adoption on a large scale did not take place until the development of the hydrogen-atmosphere electric furnace.

Hydrogen at temperatures above 800 C. will reduce the oxides of carbon steel and copper; and when copper is heated above its melting point in contact with carbon steel in a hydrogen atmosphere, the copper will flow freely on the surface of the steel and alloy with it. Furthermore, in the presence of a reducing atmosphere, the capillary action of liquid copper between two pieces of steel in close contact is very pronounced.

In the copper-brazing process, the assemblies are put together, and the parts located by means of spot welding, pressing, swaging, etc., to prevent them from slipping or moving while the copper is in liquid state. Copper, in some such form as wire, is applied near the joint, and the complete assembly then passed into an electric furnace at a temperature of approximately 1140-1150 C. After the copper melts and flows, the assemblies are passed into a cooling chamber where the copper-iron alloy formed at the joint solidifies and they cool to approximately room temperature.

Applications—

Copper brazing is largely applied to assemblies made of low-carbon steel in the form of punchings and screw-machine parts, which can be heated in a furnace. However, alloy steels, such as nickel, nickel-chromium, molybdenum-chromium-vanadium, etc., can be copper-brazed and afterwards heat-treated to develop high strength and hardness. The high-chromium steels (stainless variety) do not lend themselves readily to copper brazing unless protected against oxidation by copper plating, due to the fact that the chrome oxides are not reduced by commercially pure hydrogen at brazing temperatures.

Figure 16 shows an example of an assembly fabricated by copper brazing.

Design—

There are certain basic qualities that must be observed if copper-brazed joints are to be strong and leakproof.

Cleanliness: Especially where pressure-tight joints are required, the parts making up the assembly must be thoroughly cleansed of all oil films or other foreign matter.

Joint Openings: Joint openings (gaps) should not exceed 0.001 inch. Metal-to-metal contact is desirable.

Stable Preassembly: Assemblies should be so designed that they can be spot-welded, staked, crimped, swaged, or otherwise fastened to prevent slippage or movement of the parts while they are heat-expanded in the furnace and the copper is liquid at brazing temperature.

Strength of Joints—

The strength of copper-brazed joints on low-carbon steel is about 20,000-23,000 pounds per square inch in shear with 0.003-inch gap in the joint. With snug-fitting joints, the strength increases to about 26,000-30,000 pounds per square inch; and with press fits, the shear strength may equal the shear strength of low-carbon steel, which is about 33,000 pounds per square inch.

SILVER BRAZING.

Whereas copper as a brazing alloy is limited in its use to high-melting-point materials (copper-brazing temperature—1100 C.), such as carbon steel, nickel, and tungsten, silver-brazing alloys have melting points varying from 635 C. to 850-900 C., depending upon the composition. For this reason, they find their greatest usefulness in connection with nonferrous materials, such as copper, brass, etc., and for steel assemblies which do not lend themselves to furnace brazing, or where it is desirable to braze at lower temperatures, as in the case of stainless steel.

The principal properties of the more common silver-brazing alloys are given in Table VI.

Alloys—

Silver-brazing alloys are basically brazing spelter (60 copper—40 zinc) which have been modified by the addition of silver or other alloys to obtain lower melting points, improve fluidity, better melting properties, and higher strength.

For the majority of cases, the alloys listed in Table VI meet most requirements.

DESIGN OF JOINTS.

As in copper brazing, silver-brazing alloys should not be used as fillers or in V joints. They flow freely into narrow openings, and the strongest joints are obtained when the clearances are small.

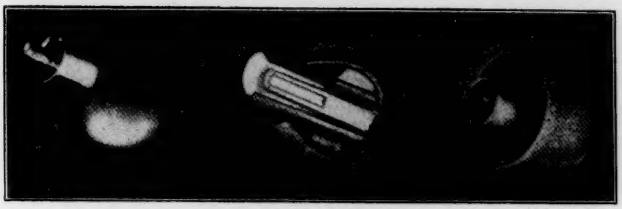


Fig. 12. Doorknob made by die casting and subsequent cold forming of the skirt

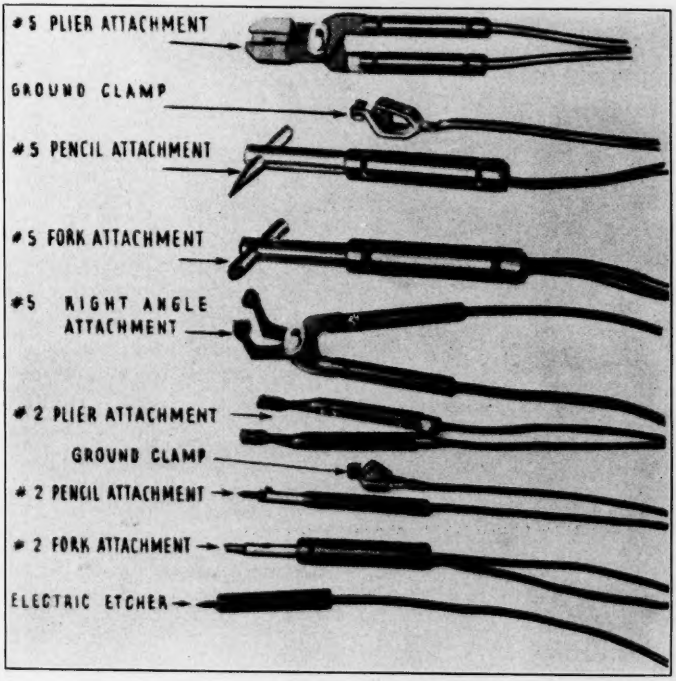


Fig. 15. Various types of electric resistance-soldering tools

Fig. 16. Steel-fin condensing unit made up of cupped fins telescoped together. This assembly has 729 joints, all copper-brazed in a single trip through a continuous furnace

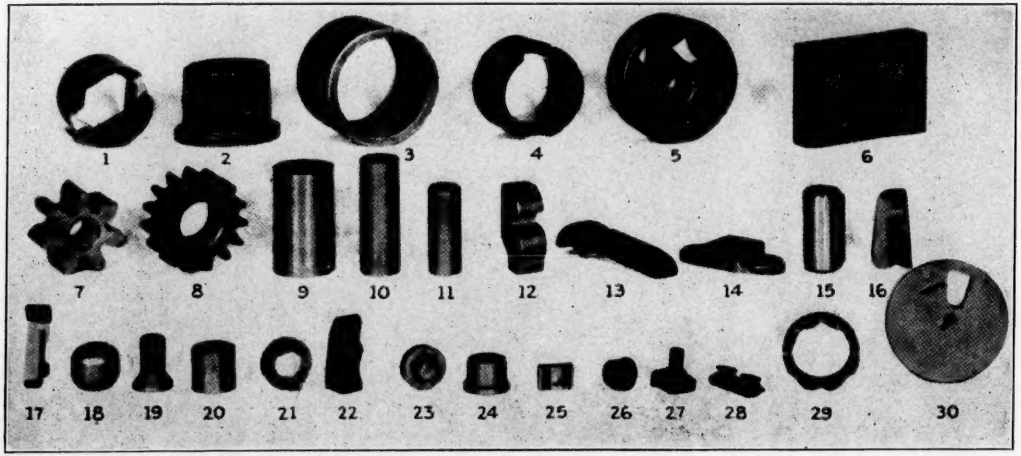


Fig. 18. Miscellaneous parts made from pressed powders (approx ⅓ actual size)

Legend:
1, 3, 9, 10, 11, 18, 19, 20, and 24—Bronze bearings and bushings of the self-lubricating type.
2 and 4—Self-lubricating bushings made from iron powders.
5 and 7—Automotive oil-pump iron parts.
6—Magnetic chuck composed of alternate layers of rolled steel and sintered bronze.
8—Self-lubricating iron gear used in electric washer.
12, 21, 23, 25, 27, and 30—Miscellaneous parts made from mixtures of copper and tin powders.
13, 14, 16, 17, and 22—Iron dovetails and brackets, chiefly automotive.
15—Self-lubricating spline bearing made from iron powder.
26—Porous-bronze cone used as an oil filter, to replace one of ceramic materials.
28—Cutter made of Carboloy powder.
29—Bronze bearing race.

TABLE VI: SILVER-BRAZING ALLOYS

Alloy as Designated in this Article (and by General Electric Co.)	COMPOSITION, PER CENT					Lowest Melting Point, C	Brazing Temperature, C	Remarks
	Silver	Copper	Zinc	Cadmium	Phosphorous			
B20F2	50	34	16	..	..	690	775	General-purpose alloy. Wide melting range permits large fillets to be built up.
B20F5	50	16	16	18	..	627	635	General-purpose alloy. Fine flowing qualities.
B20A4	30	38	32	..	..	745	790	Low-cost alloy. Use on heavy work where overheating danger is not great.
B20A6	15	80	..	..	5	640	700	Use on practically all copper-copper joints. Self-fluxing on copper. Suitable for brass, using flux. Never use on steel; embrittlement results.

Shear or lap-type joints are the most reliable, simple, and easiest to braze, therefore joints should be designed for shear wherever possible. The electrical resistance of lap joints is no greater than that of the lightest member of the joint. On copper-to-copper joints brazed with the alloy designated as B20A6 in Table VI, a lap 1½ times the thickness of the lightest member will give joints whose conductivity is equal to that of the solid unbroken conductor beyond the joint. The shear strength of a lap joint can be calculated, based on shear strength value of 25,000 pounds per square inch for silver-brazed joints.

Scarf joints in some cases may be necessary to avoid a lap joint, and offer some increase in strength and conductivity over a straight butt-type joint. A common instance where scarf-type joints are used is in connecting rectangular copper bars to form a continuous-length copper rod for edgewise-wound coils. Where scarfed joints are used as a conductor, the general practice is to braze the joint with B20F2 alloy, since this alloy has higher conductivity than B20A6.

Butt joints are necessary at times, and when they are the surfaces should be milled or machined square and even. The use of jigs to maintain tight fits is also desirable.

It is always advisable to maintain close relationship between the cross-sectional areas of the two brazed members.

Figure 17 is based on tests using alloy B20F5. The tensile strength of the brazing alloy in wire form is about 56,000 pounds per square inch, and that of the 18-8 stainless steel used was about 160,000 pounds per square inch.

Brazing Procedures—

Cleaning: Experience has shown that too much emphasis cannot be placed on the necessity of properly cleaned surfaces to be joined. These surfaces must be free from oil, grease, oxide scale, or other foreign materials. Such cleaning processes as acid dipping, steel-grit blasting (not sand blasting), or hand cleaning with emery cloth or paper are often used.

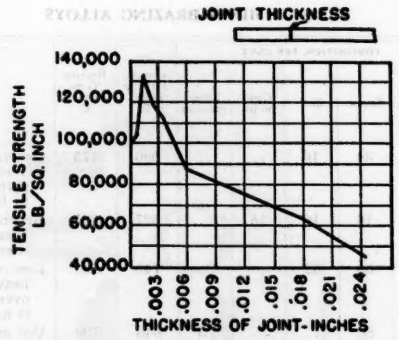


Fig. 17. Tensile strength of silver-brazed butt joints for different thicknesses of stainless steel to stainless steel

Flux and Fluxing: Silver-brazing alloys, like solders, require a suitable flux, except when brazing copper to copper with B20A6. In this case, the phosphorus in the brazing alloy deoxidizes the copper surface, making for good wetting between the copper and the B20A6 brazing alloy. In all other cases, a flux is necessary.

Brazing fluxes serve the same purposes as soft-soldering fluxes.

Just because a good flux will dissolve oxides does not excuse carelessness in cleaning prior to brazing. Thorough preliminary cleaning will be far less troublesome than depending upon the flux to do the cleaning.

Applying the Brazing Alloy: For torch brazing, the alloy may be melted into the joint from wire manipulated by the operator. When production warrants, preformed washers or rings of brazing wire are placed at the joint. This method must be used in furnace brazing. For resistance brazing especially, thin sheets of the alloy are frequently placed between the flat surfaces to be joined, thereby obtaining good distribution and economy of the brazing metal.

Methods of Heating—

The method of heating deserves full consideration for it is a factor governing the economies of the brazed joint, as well as the quality of the job. In the following is given a brief outline of available heating methods.

Gas (torch brazing): A combination of fuels, such as oxygen with acetylene, hydrogen, city gas, or natural gas is most commonly used. When using a torch, the heat is applied to the parts away from the joint to bring both members up to the brazing temperature uniformly. A neutral or reducing flame is always used except when brazing tough-pitch copper, for which type of copper an oxidizing flame is used to avoid embrittlement.

Metal-bath Brazing: This is a dip brazing process wherein the filler metal is obtained from the molten-metal bath. For a number of reasons, it is confined to joining comparatively small work, such as light-gage wire.

Chemical Bath: This method of heating requires that the assembled parts, with the brazing alloy in place, be carefully supported by suitable jigs. It has the advantage of heating the members quickly and, at the same time, providing protection from the oxidizing effect of the atmosphere. The temperature is easily controlled in this process. The size of the chemical bath

will depend upon the size and weights of the assemblies that are to be brazed, but in general these baths should be large enough so that there is no appreciable drop in the temperature of the bath when the assembled units are immersed.

Arc Brazing: This is a process wherein the heat is obtained from an electric arc that is formed between the base metal and an electrode, or between two electrodes. This process is used very little in brazing.

Induction Brazing: This method of heating, as applied to brazing, is comparatively new. It is quick in operation, provides for localization of the heat, and is applicable to non-magnetic as well as to magnetic materials.

Resistance Brazing: This is an electric brazing process wherein the heat is obtained by passing an electric current through the parts being brazed. Carbon-block brazing falls in this group, and is a common method of heating. Briefly, the equipment consists of a transformer (5-10 or 20 kva) and brazing tongs, either portable or stationary, used to hold the carbon electrode.

Resistance-welding machines are sometimes adapted to this method of brazing. In some cases, by means of thyratron control and tungsten electrodes, a high current at controlled timing is passed through the joint, brazing it in a very short period of time.

Resistance brazing has the following advantages:

(1). Heat plus pressure.
(2). Rapid heating.
(3). Easy control of heat.
(4). Reduced hazard of flame.
(5). Easily learned by untrained men.

Furnace Brazing: The adaptation of furnace brazing to silver-brazing alloys is comparatively new. It is being adapted to the brazing of high-production small assemblies and to large-unit construction involving many joints, such as heat exchangers. Two brazing alloys cover most requirements: B20A6 for copper-to-copper or copper-to-brass joints, and B20F5 for copper-to-steel or brass-to-steel joints.

In the design of joints, a gap of about 0.003 inch is desirable when furnace brazing with silver-brazing alloys. Silver-brazing alloys do not have the fluidity of copper in furnace brazing, and it is necessary to use a flux since hydrogen or other reducing gases will not reduce zinc oxide (zinc is present in all brass and most silver-brazing alloys).

Special Precautions—

Brazing 18-8 Type Stainless Steel: The 18 chromium—8 nickel type stainless steel can be silver-brazed with very good success. In most instances, the brazing alloy B20F5 is preferable because of its lower melting point.

There is one condition, however, which necessitates special precautions. The brazing temperature required to silver-braze is in the carbide-precipitation temperature range for this type material, and where 18-8 is brazed it is important to use a columbium-bearing 18-8 stainless steel. The addition of columbium to 18-8 tends to prevent the formation of carbide at the grain boundaries, and this reduces the dangers of inter-granular corrosion.

Silver-brazing Copper: When silver-brazing copper with a gas torch or when furnace-brazing in a reducing atmosphere, always use oxygen-free copper to avoid copper embrittlement. If it is necessary to braze tough-pitch copper, be extremely careful to avoid a reducing-gas flame, which would embrittle the copper. Use plenty of flux and an oxidizing flame.

ALUMINUM BRAZING.

The brazing of aluminum, like any other metal, depends upon the availability of aluminum alloys with melting points lower than the parent metal and of fluxes which will dissolve oxides at brazing temperature. Such alloys and fluxes were not available until early in 1939 when the Aluminum Company of America announced that their Research Laboratory had perfected suitable filler alloys and fluxes for brazing the following aluminum alloys:

2S—Commercially pure aluminum.

3S—1.2 per cent manganese, balance aluminum.

61S—0.55 per cent silicon, 0.95 per cent magnesium, 0.25 per cent copper. 0.25 per cent chromium, balance aluminum.

The filler or brazing alloy varies with the parent alloy. The fluxes are basically fluoroxide salts with other constituents added to vary their melting point. (Flux must be fluid and active at brazing temperature.)

The filler material is usually applied in the form of wire or sheet washer in a manner similar to the method used in the other metals. Sheets of 2S and 3S can be obtained with an "Alclad" brazing alloy coating integral with the parent sheet. The design of joints follows largely that of copper-brazed joints.

For brazing aluminum several methods of heating may be employed: namely, furnace, torch, or dipping in molten flux.

The strength of brazed joints in aluminum alloys is about the same as the strength of torch-welded joints in the same material.

Typical values of strength of furnace-brazed butt joints of aluminum are given in Table VII.

TABLE VII

STRENGTH OF ALUMINUM-BRAZED BUTT JOINTS

Alloy	Tensile Strength Lb per Sq In.	Per Cent Elongation
2S	15,000	7.0
3S	19,000	3.0
61S	* 34,000	3.0

* Heat-treated condition.

It should be borne in mind that the temperature at which brazing is done will anneal aluminum alloys. Parts that are made of 2S or 3S will be fully annealed when furnace- or dip-brazed. For maximum physical strength, 61S relies on heat-treatment and it is possible to heat-treat parts brazed of 61S alloy. Sometimes the brazing cycle and heat-treatment can be combined (particularly in furnace brazing).

Since the filler alloys are aluminum-base alloy, there is no marked electrolytic corrosion of aluminum-brazed joints, as in the case of soldered joints, and brazed joints should be satisfactory for many industrial applications.

POWDER METALLURGY.

Powder metallurgy is essentially a process whereby a metallic part is produced from powders of a single metal, of several metals, or of a combination of metals and nonmetals, which, after thorough mechanical mixing, are compacted under high pressures into the required shape and afterward sintered at elevated temperatures, but below the melting point of the major constituent. Diffusion causes all particles to unite into a solid cohesive mass partaking to a varying extent (depending on the compacting pressure, time, and sintering temperature) of the same chemical and mechanical properties as the identical composition produced by melting the various constituents together.

Powder methods are used to make parts which cannot be produced by other means or which cannot be produced as well or as economically by other methods (machining, casting, etc.).

Metals such as tungsten, molybdenum, tantalum, and columbium, whose melting points are too high for conventional melting and casting, are fabricated by this method. For instance, tungsten powder is pressed into briquettes and sintered at a temperature well below its melting point. The briquettes are forged or swaged into rods which may be drawn into wire 0.001 inch in diameter and finer, with a tensile strength as high as 590,000 pounds per square inch.

Self-lubricating bushings and bearings are made from iron powders, mixtures of iron and copper powders, and from mixtures of copper and tin powders. Fine interconnected pores are produced in the sintered compact by admixture of certain non-metallic elements which volatilize in sintering, or by adjusting pressure and sintering temperature. Impregnation with oil after pressing and sintering furnishes a constant supply of lubricant to the surface by surface tension.

Contact buttons are made, combining the high conductivity of copper or silver with the resistance to fusion at high arcing temperature of such metals as tungsten, molybdenum, nickel, etc.

Cemented-carbide high-speed cutting tool bits are made by mixing the fine carbide particles with nickel or cobalt powders. On pressing and sintering, the nickel or cobalt forms a binding matrix for the carbide cutting medium.

To make current-carrying brushes, copper and graphite powders are sintered together to combine the high conductivity of copper with the lightness and lubricating properties of graphite. These brushes can be pressed from flake copper so that they show a laminated layered structure with quite low resistance in the direction parallel to the laminations.

The use of powder parts to replace other fabrication methods as a means of reducing cost is steadily increasing. Since the process permits forming to exact dimensions, with smooth surface and sharp outlines, expensive machining operations and costly scrap losses can be eliminated. Tolerances of sintered parts are on the order of approximately $\pm$ 1 mil per inch, in the plane perpendicular to the direction of pressing, and about $\pm$ 5 mils in the other plane. Closer tolerances can be obtained by cold-pressing after sintering. The economic usefulness of this process is particularly great for iron parts, where there is no competition from other low-cost production methods like metal-mold or plaster-of-Paris castings, as in the case of aluminum and the copper alloys.

Parts can be subjected to ordinary fabricating methods, such as forging, swaging, grinding, welding, machining, etc. If surface pores are to be kept open, it is necessary to use sharp tools. Sintered carbide tools are recommended. The parts can be plated and iron parts can be hardened.

Physical properties of powdered-metal parts are as a rule not quite so good as of corresponding compositions produced by customary methods, particularly ductility and shock resistance. Mechanical properties depend on pressure and sintering temperature. Greater pressures and higher sintering temperatures will produce higher strength, but higher pressures increase die wear; higher temperatures increase sintering shrinkage with corresponding loss of accuracy, unless provided by subsequent cold pressing.

The costs of dies for this process are comparable with mold costs for plastics; their life is relatively short. Large, powerful, and expensive presses are required since pressures of the order of 20 to 30 tons per square inch are used. This, together with the fact that metal powders are still quite expensive, although the cost is steadily coming down, makes it essential that, for economy, where powder-metal parts are contemplated, only large-production quantities with great savings per piece be considered, in order to justify the method.

The design must be such that the part can be produced by a single downward stroke of the plunger of the press. The fact that metal powders do not behave as perfect liquids under pressure, due to interparticle friction and friction on the die walls, imposes some limitations on the shape and size of the parts to be so made. Designers wishing to use powdered-metal parts should consult the process expert in their plant to assure workable design. Many powdered-metal parts, iron and bronze, are already being used in the form of bearings, bushings, pinions, cams, gears, etc.

Careful study of the designs shown in Figure 18 will give an indication of the possibilities and limitations of the method.

THE ICE BREAKER *ERNEST LAPOINTE.*

The twin-screw ice-breaking and channel-surveying vessel *Ernest Lapointe,* built in Canada for the Canadian Department of Transport, is described in this article reprinted from the January, 1942, issue of The Shipbuilder and Marine Engine-Builder.

The part which the industries of Canada are playing in maintaining an Empire war effort of unparalleled volume has justifiably been given considerable publicity for the benefit of the world at large and of Great Britain in particular. The people of this country have good reason to realize the potential as well as the ever-increasing actual industrial strength of the Dominion, more remote as it fortunately happens to be from black-out inconveniences and air-raid stoppages of output.

While the geographical position of Canada, in that it is fairly beyond the range of the prevailing methods of attack of the Axis powers, is of inestimable advantage, the approach of winter brings with it a most serious disadvantage which accrues from the climatic conditions in this northern part of the American continent. It will certainly be no secret from the enemy that the River and Gulf of St. Lawrence become ice-bound, the main shipping artery of the Dominion being thus closed until the spring; and it will readily be appreciated that the need for forcing a channel through the ice on the St. Lawrence River is indeed an urgent one. The policy of the Canadian Government in regard to the maintenance of efficient and effective units for use in ice-breaking, as well as for channel survey and inspection, has always been a realistic and progressive one. While the importance of opening the St. Lawrence to shipping is, of course, a paramount reason for the care and expense given to this branch of Canadian transport, it should

be borne in mind that there exists a second and very important incentive for the ice-breaking activities to which reference has been made.

If the ice which so effectively binds a waterway is left to disappear as the atmosphere becomes warmer, no attempt being made by artificial means to assist the disintegrating progress of the change of seasons, there is a very acute danger of ice jams being formed in various regions, leading to floods of gigantic proportions, with accompanying devastation and loss of life and property. Following an unusually high tide on the River St. Lawrence in 1886, a Royal Commission advised the use of ice-breaking units in assisting to break down the vast accumulations of ice which formed during the month of December. Since 1904, ships specially designed, as well as others strengthened and converted, for this purpose have been used in the river, with very successful results. The largest unit in the Canadian ice-breaking fleet is the twin-screw steamship *N. B. McLean*, of 3254 tons gross, this vessel, which was built at Halifax, Nova Scotia, being designed particularly for ice-breaking. The units of the Government's fleet, which included the *Champlain, Montcalm, Lady Grey, Bellechase, Mikula* and *Saurel*, have been assisted to some extent by other ships built for purely commercial undertakings. The last-mentioned vessels included the triple-screw car ferry and ice-breaker *Leonard*, built to the order of the Trans-continental Railway Company, of Canada, for service between Quebec and Levis, and the triple-screw ice-breaking car-ferry steamship *Charlottetown*, constructed to the order of the Canadian National Railways for transport purposes between New Brunswick and Prince Edward Island.

Considerations of Design.

While admitting the importance of the need for ice-breaking vessels in localities such as those detailed in the foregoing paragraphs, the policy of the Canadian Government in this, as in every other matter, must be one which is based on sound economic lines. Thus, when it became apparent that the ice-breaking and channel inspecting and surveying fleet of the Department of Transport required some additions, *viz.*, one new ice-breaker and one survey unit, an investigation was carried out to determine whether a dual-purpose craft could be evolved.

The primary difficulty in the problem under consideration was, of course, that the first type of vessel required a much larger-powered installation of propelling machinery than the second. It was eventually ascertained that, if superheated steam was used in conjunction with a particular form of high-efficiency reciprocating engine, it was possible to run a surveying vessel possessing the power of an ice-breaker at less cost than that of the older types of comparatively low-powered survey craft. The engine which enabled this advantageous state of affairs to be realized was the well-known Christianson & Meyer type. the economy shown resulting in the adoption of this form of propulsion in the dual-purpose vessel which was eventually designed and constructed, *viz.*, the *Ernest Lapointe*.

The *Ernest Lapointe* was designed by the Canadian Department of Transport, and was built under special survey by the Davie Shipbuilding & Repairing Co., Ltd., of Lauzon, Levis, Quebec. These shipbuilders, it may be noted, constructed the *Charlottetown*, to which earlier reference has been made. The new ice-breaker is classed ✠ 100 A.1 by Lloyd's Register of Shipping, and embodies numerous improvements and refinements suggested by many years of patient study of the particular problems, prevailing in the River and Gulf of St. Lawrence.

The principles involved in ice-breaking are the subject of an informative article by Ing. N. Gouljaeff published in a previous edition of this journal. In this, the author divides ice-breakers into two classes, *viz.*, (1) those

which cut the ice by a ramming action, attaining best results with broken-up and floating ice, and with openings between separate ice-fields, and (2) those ships which have a spoon-shaped bow, with rounded sections forward, and in which the weight of the ship is used to crush a channel in the ice. The second type he mentions are most suitable for dealing with compact uniform ice-fields, heaped-up blocks of ice or pack ice. It is interesting to note that Ing. Gouljaeff refers to the principle—first advocated by an American engineer, Mr. Frank E. Kirby—of using a bow propeller to create a vacuum under the ice forward of the ship when going forward, and of driving water forward with this propeller when going astern, so as to wash away packed ice and snow.

Following the discovery of Professor Barnes, of Montreal University, that if ice and snow are subjected to the action of water only 1 degree C. above their own temperature, a corroding effect which would entirely remove them is produced, it has become the practice in some ice-breakers (*e.g.*, the *Leonid Krasin* and *Lenin*) to lead the circulating water to an ejection point at the stem, instead of at amidships, so as to assist in the disintegration of the ice formation. A further step in the technique of ice-cutting was that designed in 1936 by a Soviet engineer, Mr. B. Chizhikov, and which consisted of the practice of playing two or three jets of water at high velocity and pressure on the ice at the bow. The foregoing methods form an interesting contrast with that adopted for the *Ernest Lapointe* as described in the following paragraph.

The design of the *Ernest Lapointe* follows that of the *N. B. McLean* in that only stern propellers are provided, but an innovation has been introduced in that the shape of the ship forward has been arranged so that the bow wave is used to accomplish ice-breaking. This theory—which, it is believed, has been advanced for the first time by the responsible officials of the Canadian Department of Transport—has been substantiated in practice with the vessel under discussion, and has been found to be particularly applicable in breaking out the ice in shallows bordering the navigating channel.

The principal dimensions, etc., of the *Ernest Lapointe* are as given in Table I., while the general arrangement is reproduced on Plate I.

TABLE I.—LEADING PARTICULARS OF THE "ERNEST LAPOINTE."

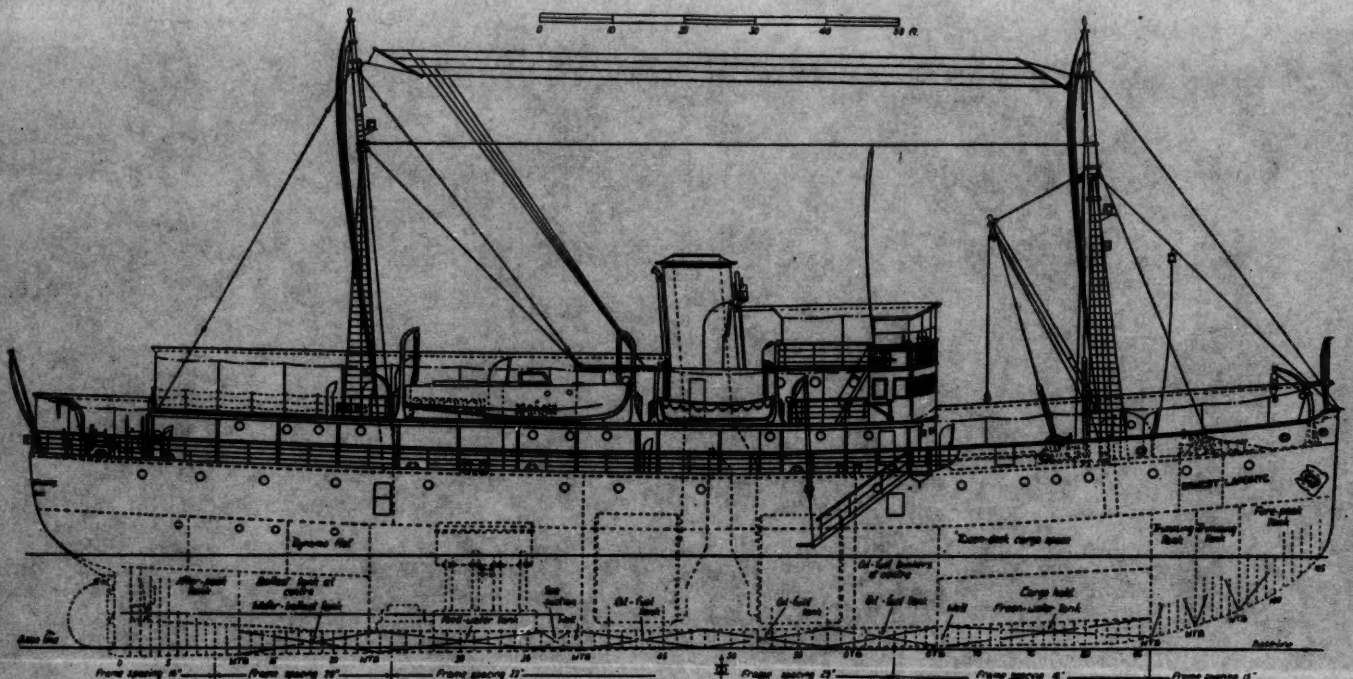
Length overall	184ft. 3in.
Length B.P.	172ft. 0in.
Breadth moulded	36ft. 0in.
Depth moulded to upper deck	17ft. 0in.
Draught	13ft. 0in.
Corresponding displacement in fresh water, tons	1,540
Designed I.H.P., total, port and starboard	2,000
Designed revs. per minute	140
Number of propellers	2

GENERAL ARRANGEMENT.

From the general-arrangement profile reproduced on Plate I., it will be seen that the *Ernest Lapointe* is a complete superstructure-type vessel of a most compact design, with a "closed" shelter 'tween decks. It was found possible to arrange the required public rooms and staterooms in houses forward, between and abaft the engine and boiler casings, giving a combined

THE CANADIAN TWIN-SCREW ICE-BREAKING AND CHANNEL-SURVEYING VESSEL "ERNEST LAPOINTE."

Built by the Davie Shipbuilding & Repairing Co., Ltd., and engined by Marine Industries, Ltd.



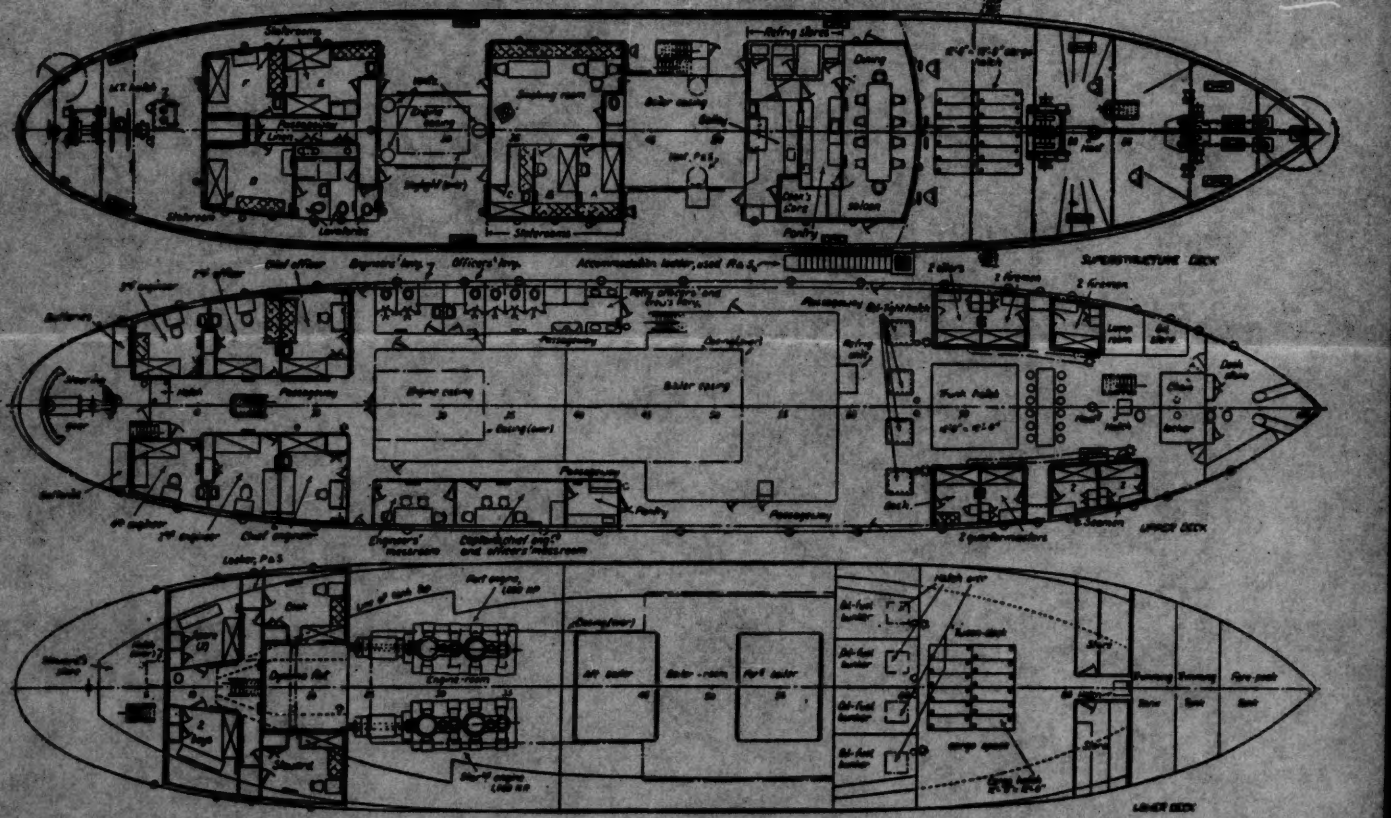
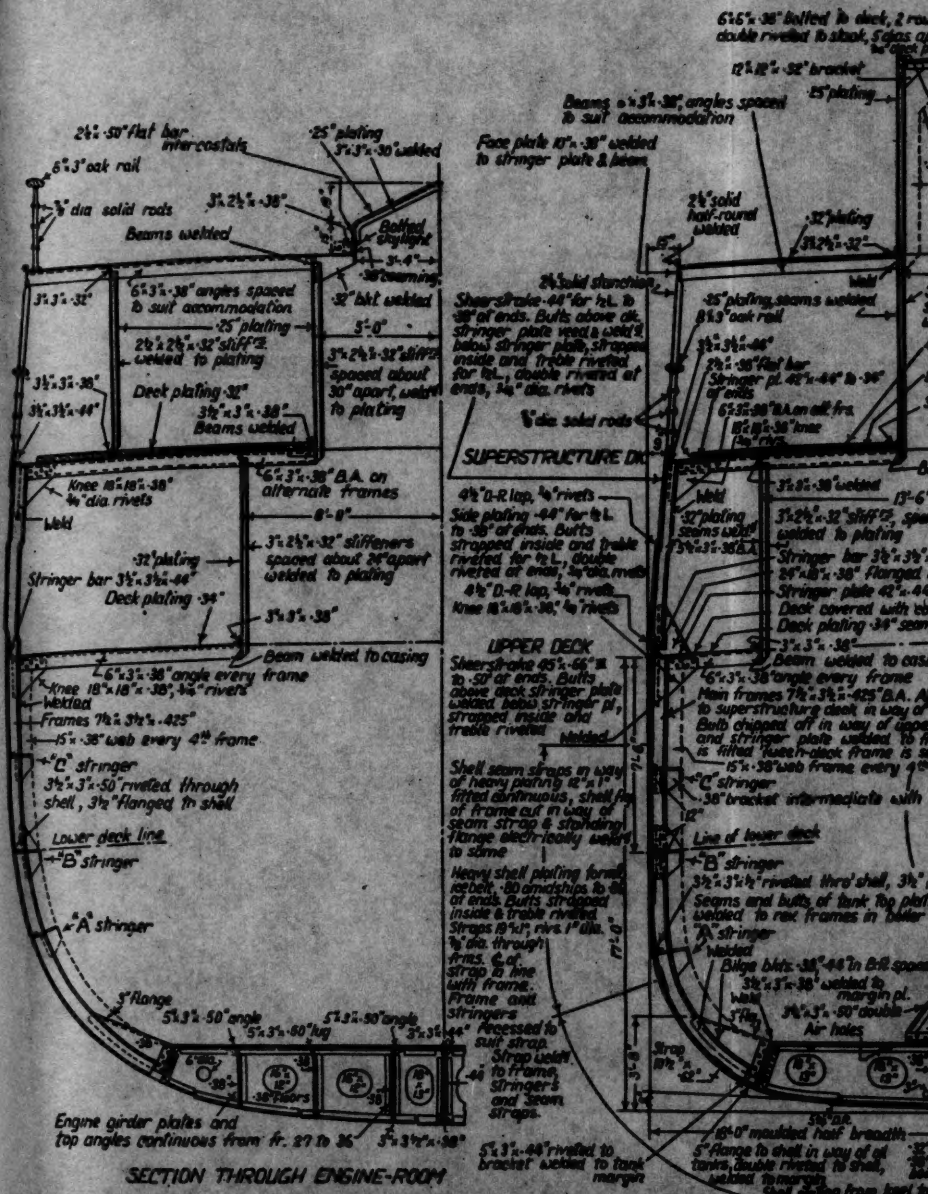
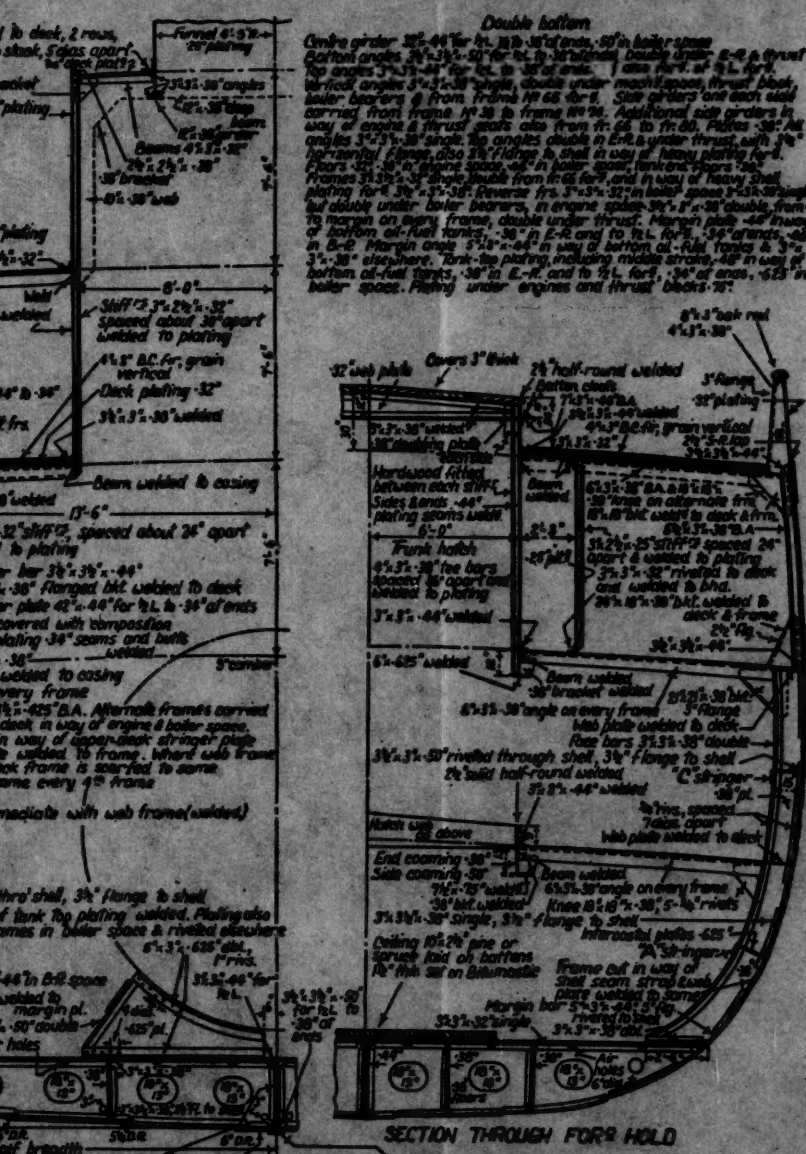


PLATE I.


2½"x·59" flat bar intercostals
·25" plating
3"x3"x·36" welded
6"x3" oak rail
⅞" dia. solid rods
3"x2½"x·38"
Bolted skylight
Beams welded
3'-4"
·38" coaming
3"x3"x·32"
6"x3"x·38" angles spaced to suit accommodation
·25" plating
·32" bkt. welded
3'-0"
2½"x2½"x·32" stiffs welded to plating
3"x2½"x·32" stiffs spaced about 30" apart, weld to plating
3½"x3½"x·38"
3½"x3½"x·44"
Deck plating ·32"
3½"x3"x·38" Beams welded
6"x3"x·38" B.A. on alternate frames
Knee 18"x18"x·38" ⅝" dia. rivets
Weld
8'-8"
·32" plating
3"x2½"x·32" stiffeners spaced about 36" apart welded to plating
Stringer bar 3½"x3½"x·44"
Deck plating ·34"
3"x3"x·38"
Beam welded to casing
6"x3"x·38" angle every frame
Knee 18"x18"x·38" ⅝" rivets
Welded
Frames 7½"x3½"x·425"
15"x·36" web every 4th frame
"C" stringer 3½"x3"x·50" riveted through shell, 3½" flanged in shell
Lower deck line
"B" stringer
"A" stringer
5" flange
5"x3"x·50" angle
5"x3½"x·60" lug
3"x3½"x·44"
·38
·38 floors
Engine girder plates and top angles continuous from fr. 27 to 36
5"x3½"x·38"
SECTION THROUGH ENGINE-ROOM
Beams 3"x3"x·38" angles spaced to suit accommodation
Face plate 10"x·38" welded to stringer plate & beam
2½" solid half-round welded
·32" plating
2½" solid stanchion
Shear-Strake ·48" for ½L & ·38" at ends. Butts above dk. stringer plate vee'd & weld'd, below stringer plate, strapped inside and treble riveted for ½L, double riveted at ends, ¾" dia. rivets
⅞" dia. solid rods
SUPERSTRUCTURE DK
4½" D-R lap, ¾" rivets
Side plating ·44" for ½L to ·38" at ends. Butts strapped inside and treble riveted for ½L, double riveted at ends, ¾" dia. rivets
4½" D-R lap, ¾" rivets
Knee 18"x18"x·38", ⅝" rivets
UPPER DECK
Sheerstrake 45"x·56" to ·50" at ends. Butts above deck stringer plate welded, 8" inner pl., strapped inside and treble riveted
Welded
Shell seam straps in way of heavy plating 12"x1" fitted continuous, shell fay of frame cut in way of seam strap & stanchion flange electrically welded to same
Heavy shell plating forward, ·80 amidships to ·44 at ends. Butts strapped inside & treble riveted
Straps 15"x1", rivs. 1" dia. ⅞" dia. through frms. C of strap in line with frame. Frame cut & stringers recessed to suit strap. Strap welded to frame, stringers & seam straps.
5"x3"x·44" riveted to bracket welded to tank margin
·25" plating, seams welded
8½"x3" oak rail
3½"x3½"x·46"
2½"x·38" flat bar
Stringer pl. 45"x·44" to ·36" at ends
6'-3½"x·38" B.A. on alt. frs.
15"x15"x·38" Inner
⅞" rivets
Weld
·32" plating seams welded
3½"x3"x·36" B.A.
Stringer bar 3½"x3½"
24"x·38" flanged
Stringer plate 42"x·44"
Deck covered with
Deck plating ·34" seam
3"x3"x·38"
Beam welded to casing
6"x3"x·38" angle every frame
Main frames 7½"x3½"x·425" B.A.
to superstructure deck in way of
Both chipped off in way of lapped
and stringer plate welded to
is fitted "Isherwood" frame is
15"x·38" web frame every 4
"C" stringer
·38" bracket intermediate with
12"
Line of lower deck
"B" stringer
3½"x3½"x½" riveted thro' shell, 3½"
Seams and butts of tank Top plat
welded to rec. frames in bilge
"A" stringer
Welded
Bilge blts. ·38"·44" in B.B. spaces
3½"x3"x·38" welded to
margin pl.
Weld
3"x3"x·50" double
Air holes
5'-0" max.
15'-0" moulded half breadth
5" flange to shell in way of pt. tanks, double riveted to shell, welded to margin
Strap 8½"x·42"
Shell plating from keel to turning bilge ·54" for 0.4 of ht. Butts strapped & riveted. Seams 25% Hole
Air rivets ⅞" dia.

Butts of centre-girder plates welded. Centre-girder bottom angles to centre-girder plate, ⅝" rivets, spaced 5 dias. apart. Centre-girder top angles, both flanges, ⅝" rivets, 6½ dias. in engine space, elsewhere ⅝" rivets, 7 dias., except to inner bottom in boiler space, where they are welded. Vertical angles connecting centre girder and floors, ⅝" rivets, spaced 5 dias. apart, frames to floors and shell plating for 9 of frame 66, spaced 5½ dias., elsewhere ⅝" rivets, 7 dias. apart. Reverse frames to floors ⅝" rivets, 7 dias. apart. Reverse frames to inner bottom, ⅝" rivs., 7 dias. apart, except in D-R. where they are welded. Vertical angles floors and side girders, ⅝" rivets, 7 dias. apart. Side-girder top angle welded to inner-bottom plating in boiler space. Floors of bottom fuel tanks all welded. Note:- No rivets through inner-bottom plating in way of boiler space.

Fig. 1.—Midship, Engine-room and Forward-hold Section


Double bottom
Centre girder 32"×.44" for fr. 38 to 58 at ends, .50" in boiler space
Bottom angles 3½"×3½"×.50" for fr. 19 to 38 at ends, double under E-R & thrust
Top angles 3"×3"×.44" for fr. 19 to 38 at ends
Vertical angles 3"×3"×.38" single, double under mach'y space, thrust block, boiler bearers & from frame № 66 for fr.
Side girders one each side carried from frame № 38 to frame № 94. Additional side girders in way of engine & thrust seats also from fr. 66 to fr. 80. Plates .38" Angles 3"×3"×.38" single. Top angles double in E-R & under thrust, with 3½" horizontal flange, also 3½" flange to shell in way of heavy plating for fr.
Floors .32" to engine space, .40" in boiler space, tank end plates .44"
Frames 3½"×3½"×.38" single, double from fr. 66 forr, and in way of heavy shell plating for fr. 38 to fr. 58. Reverse frs. 3"×3"×.32" in boiler space 3"×3"×.38" single, but double under boiler bearers, in engine space 3½"×3½"×.38" double, from ℄ to margin on every frame, double under thrust. Margin plate .40" in way of bottom oil-fuel tanks, .38" fr. E-R and to ½ L. for fr. .34" at ends, .40" in E-R. Margin angle 5"×3½"×.44" in way of bottom oil-fuel tanks & 3"×3"×.38" elsewhere. Tank-top plating, including middle strake, .40" in way of bottom oil-fuel tanks, .38" in E.-R. and to ½ L. for fr. .34" at ends, .625" in boiler space. Plating under engines and thrust blocks .75"
Covers 3" thick
.32" web plate
2½" half-round welded
Bottom cleat
Hardwood fitted between each stiff'r
Sides & ends .44" plating seams welded
Trunk hatch
Beam welded
Deck plating .32"
Beam welded to casing
Stiff'r 3"×2½"×.32" spaced about 36" apart welded to plating
Frame 6'-5½" .28" plating
Beams 4½"×3½"×.38"
Bracket .38"
Web .38"
Frames 8'-0"
Frame 13'-6"
Bar 3½"×3½"×.44"
Plate 42"×.44" for ½ L & .34" at ends
Covered with composition
Plating .34" seams and butts welded
Frame 5'-0"
Frames every 4th frame
Web frame (welded)
Thro' shell, 3½" flange to shell
Tank Top plating welded. Plating also frames in boiler space & riveted elsewhere
Plate .44" in Bilge welded to margin pl.
Double plate .50" holes
Plate .50" for ½ L. to .38" at ends
Plate .44" for ½ L. to .38" at ends
Plate .50" in boiler space
Plate .32" for ½ L. to .28" at ends
Plate .32" for ½ L. to .25" at ends
Beam .38" bracket welded to deck
Plate .34" at ends
Beam .38" bracket welded
Beam welded to casing
Every frame
Plate .625" B.A. Alternate frames carried to deck in way of engine & boiler space, & in way of upper deck stringer plate & welded to frame. Where web frame not frame is scarfed to same, same every 4th frame
Associate with web frame (welded)
Plate .625" for ½ L. to .38" at ends
Plate .625" pl.
Plate .75" for ½ L. to .38" at ends
Plate .75

erection approximately 112 feet long on the superstructure deck; while the captain's accommodation and the wireless-telegraphy office and operator's cabin have been placed in a deckhouse on the boat deck forward and abaft the boiler casing. As it was convenient to house the officers, engineers and crew in the shelter 'tween decks and in a lower 'tween decks aft, it was not necessary to provide either a forecastle or a poop erection. To give the required height of weather deck forward, a forward sheer much above that necessary to comply with freeboard requirements has been adopted, while a 4-foot bulwark from the stem to the fore end of the midship deckhouse assists in keeping the superstructure deck as dry as possible in a seaway.

The graceful appearance of the *Ernest Lapointe* is enhanced by the considerable amount of rake given to the funnel, fore mast and main mast.

The keel rises forward over a distance of about 30 feet, merging into the line of a well-rounded stem, the fore end in profile being generally similar to the usual practice adopted in ice-breakers where there is no propeller forward. It is in the transverse shape of the ship that new lines have been worked upon in evolving a hull which, as mentioned previously, will generate a bow wave of such a form as will assist in carrying out ice-breaking operations. The stem is a nickel-steel casting, V-shaped and rabbeted to take the shell plating, and is solid for about 16 feet in way of the region of the ice-breaking line. Elsewhere, the stem casting is gulleted to give a lighter construction, suitable webs being provided for attachment to decks and breasthooks.

A modified cruiser stern has been adopted, the contour being rounded in profile so that a relatively short overhang of stern is presented in way of the ice-breaking region; while the increased overhang of stern between the upper and superstructure decks facilitates housing the steering engine. The stern-frame is also of cast steel, the two parts of which it is comprised being rabbeted to take the shell plating. The upper casting includes a special trunk for the protection of the rudder stock in way of the load water-line.

The rudder is of the unbalanced, double-plate type and is fitted with three pintles, the connection to the rudder stock being by means of a horizontal coupling. As might be expected in a vessel which has to navigate among ice, the bossed framing and plating over the twin shafts have been made of specially heavy design. The bossing has been carefully stream-lined and placed at the most suitable angle for propulsion. Cast-steel shaft brackets terminate the bossing.

The superstructure and upper decks are continuous. A lower deck is worked forward and abaft the oil-fuel bunker and machinery spaces. The boat deck, referred to previously, is particularly spacious for a ship of such dimensions; while the navigating bridge is fitted above the captain's house and wheelhouse, and affords an extensive platform from which meteorological and navigational observations may be taken. It is particularly important that all-round navigating vision is obtained in the *Ernest Lapointe*, as ice-breaking operations are carried out on courses set from range lights.

The vessel is subdivided by eight transverse bulkheads which extend to the upper deck, the aftermost bulkhead being stepped aft at the lower deck to give a sufficient length for accommodation purposes on the fore side of the bulkhead. Fore and aft bulkheads in way of the oil-fuel bunkers extend to the upper deck, dividing the bunker into four tanks.

As one of the major requirements in the arrangement of an ice-breaker is that of making it possible for the ship's trim to be modified quickly for working in ice, large trimming tanks have been fitted at each end—two forward and one aft—in addition to the normal fore and after peak tanks.

The double bottom extends from the after bulkhead of the forward trimming tanks to the forward end of the after ballast tank. In way of the boiler-room and the oil-fuel deep tanks, oil fuel is carried in the double-

bottom spaces. The foremost double-bottom tank is reserved for fresh water, feed water being carried under the engines and water ballast in the aftermost double-bottom tank. The capacities of the oil fuel and water ballast available in the trimming tanks and peaks are stated in Table II.

Relatively little space is available in the *Ernest Lapointe* for the carriage of cargo, owing to the large proportion of the length required for the engine and boiler-rooms and oil-fuel bunkers. The total length of these compartments—30 feet 2 inches for the engine-room, 38 feet 4 inches for the boiler-room, and 11 feet 9 inches for the bunkers—is 80 feet 3 inches, or 46.6 per cent of the length between perpendiculars. When to this is added the proportion of the length of the ship required in which to accommodate trimming and peak tanks, it is seen that only 17.5 per cent of the ship's length, or 30 feet 0 inch, could be allocated for the hold. The crown is the

TABLE II.—CAPACITIES OF OIL FUEL AND WATER BALLAST IN TRIMMING AND PEAK TANKS

	Tons.
Oil fuel (deep tanks and double bottom), total	194
Trimming tank, frames 12 to 23 (salt water)	24
Trimming tank, frames 86 to 91 (salt water)	60
Trimming tank, frames 91 to 96 (salt water)	45
After-peak tank (salt water)	34
Fore-peak tank (salt water)	40
Total trimming capacity	203

lower deck, a 'tween-deck cargo space being provided between the lower and upper deck. bounded transversely by the hold bulkheads. As may be seen from Plate I., the cargo spaces are served through a hatchway, 12 feet square, which is trunked down between the superstructure and upper decks.

The chain locker, oil store, lamp-room and deck store are arranged at the fore end of the upper deck.

CONSTRUCTION.

The construction of such vessels as ice-breakers is always of special interest, as the increased strength and the necessity for a flush shell in the ice-breaking region peculiar to this type of ship involve a method of construction somewhat different from that adopted in normal cargo vessels.

The details of construction are best seen in Figure 1, which shows the midship, engine-room and forward-hold sections. Transverse framing has been adopted, being spaced 23 inches apart in the midship portion of the ship, while the spacing of frames is reduced to 20 inches abaft the engine-room, 18 inches in the cargo hold, 16 inches in the after peak, and 15 inches in the forepeak and forward trimming tanks. The exact terminations of the individual frame spacings are shown in the profile of Plate I. The frames have the assistance throughout the length of the ship of stringers from 3 feet 6 inches to 3 feet 9 inches apart, these longitudinals being 15 inches deep. In the engine and boiler-rooms, web frames 15 inches deep are fitted at every fourth frame, while in the cargo hold and 'tween-decks the framing generally is of a web form, as shown in Figure 1.

The flat plate keel is of particularly robust construction, being 42 inches wide and .75 inch in thickness all fore and aft. The keel plate is strapped on the inside so as to provide a flush surface for the 8 inches by 1 inch rubbing piece, fitted horizontally in section view.

The heavy shell plating which forms the ice-belt extends vertically from about 5 feet draught to 14 feet draught, the thickness varying from .80 inch at amidships to .86 inch at the ends. While the bottom-shell strakes are laid "in and out," the side shell up to the upper deck forms a flush surface to avoid catching a plate edge in the ice. Seam straps are riveted on the inside; while, to avoid joggling the frames and web-frame shell angles, the shell flanges of these angles have been cut off in way of the seam strap, the standing flanges of the angles at these points being welded to the seam strap to preserve the continuity of frame support. In a similar manner, the keel butt straps, which have been fitted with their transverse center-lines on floors, have been welded to the floors and center girder, the bottom angles of the floors and center girder being omitted in these parts.

Accommodation.

Staterooms have been arranged in the superstructure deck-houses abaft and forward of the engine casing. Accommodation is provided for seven persons in five single-berth and one two-berth staterooms. The staterooms in the aftermost deckhouse are comparatively large and well appointed, the furnishings including dressing tables and commodious wardrobes. A lavatory is provided at the fore end of the after deckhouse on the starboard side.

Two well-designed public rooms are arranged on the superstructure deck, the dining saloon extending from side to side across the front of the deck-house forward of the boiler casing, and providing seating accommodation for 10 persons. The galley, cook's store, pantry and refrigerated stores are in convenient positions adjoining the saloon.

The smoking room occupies the port side of the deckhouse between the engine and boiler casings, a toilet being provided forward of this room.

The captain's cabin is on the boat deck and has shower and toilet spaces arranged immediately aft, on opposite sides of the light and air trunk to the galley. The only other accommodation on this deck is the combined cabin and office for the wireless-telegraphy operator. The cabin is partly partitioned from the wireless-telegraphy office, and may be curtained off so as to give two separate apartments.

The chief and second officers, and the chief, second, third and fourth engineers are accommodated on the uppper deck aft in single-berth cabins. The captain's and officer's messroom and a similar room for the engineers, together with a pantry, are placed forward of this accommodation on the starboard side of the engine casing, while the officers' and engineers' lavatories are located in the corresponding position on the port side.

The petty officers' and crew's accommodation forward on the upper deck includes a single-berth cabin for the boatswain and two-berth cabins for the two quartermasters, four seamen, two oilers and four firemen. The deck on the middle-line forward of the trunked cargo hatchway provides messing spaces for the petty officers and crew, while lavoratory spaces are located amidships on the port side of the engine casing. The remaining crew's quarters include single-berth cabins for the steward and cook, a two-berth cabin for boys and a spare cabin arranged aft on the lower deck.

General Equipment.

The ship's equipment of boats includes a 28-foot motor lifeboat, 32-foot motorboat and 16-foot dinghy, all of which are arranged under mechanical

davits on the boat deck. A boat winch is fitted on the boat deck abaft the wireless-telegraphy cabin.

From the steering gear, in the compartment on the upper deck aft telemotor controls are led to control standards in the wheelhouse on the boat deck forward, on the wheelhouse top, and at a docking position on the superstructure deck aft. In the latter position, hand-steering gear is also provided.

The deck equipment not previously mentioned includes a windlass, fitted on the superstructure deck forward, a steam winch provided forward of the cargo hatchway for working the single tubular steel derrick, and a warping winch fitted aft on the superstructure deck. The windlass, already referred to, is fitted with warping drums. Bow and stern davits are fitted in stands on the superstructure deck.

Propelling Machinery.

The main propelling machinery of the *Ernest Lapointe* comprises two Christiansen & Meyer steam engines developing a total IHP. of 2000 at 140 RPM. As stated previously, the installation of these engines has resulted in such marked economy in comparison with other types of reciprocating steam engines that it has been possible to provide a survey vessel with ice-breaker power and run it at less cost than the older low-powered survey vessels. Both engines have been constructed by Marine Industries, Ltd., of Sorel, Canada, under license from the patentees, who supplied the complete drawings.

Steam is supplied at a pressure of 220 pounds per square inch and superheated 100 degrees F. by two boilers, each 15 feet 3 inches diameter by 11 feet 9 inches long, and having a heating surface of about 3000 square feet. Each boiler has three oil-fired furnaces and is equipped with superheaters in the uptake. The air supply and preheating is on the Howden system.

The Christiansen & Meyer patent double-compound engines, with semi-uniflow LP. cylinders, each have a stroke of 27.5 inches, the HP. cylinder diameter being 13 inches and the LP. cylinder diameter 28.3 inches. Each engine is designed to develop 1000 IHP., with a cut-off not exceeding 50 per cent, when supplied with steam at 220 pounds per square inch, superheated 100 degrees F.. and a condenser vacuum of 26 inches Hg. It will be seen from the trial-trip indicator diagrams reproduced in Figure 2, however, that the designed output has been considerably exceeded.

Views of these engines in the erecting shop are shown in Figures 3 and 4, from which it will be seen that the engines have double cast-iron columns and crosshead guides, contrary to the usual practice with this design of engine, which, normally, has single cast-iron columns at the back with steel pillars at the front. The double cast-iron columns were employed to allow of prolonged astern operation, which is a necessary part of the ship's work. Furthermore, and in consequence of this arrangement, Stephenson valve gear was fitted instead of the Klug gear normally used with this design of engine. It should also be noted that, because of the severe duty imposed by ice-breaking conditions, the engine scantlings are heavier than usual, and the crankshaft sizes are greater than those required by Lloyd's Register.

Messrs. Cockburns, Ltd., of Cardonald, Glasgow, supplied the combined regulating throttle and emergency valves for these engines; while Messrs. G. & J. Weir's type of regenerative condenser is fitted to each engine. Air extraction is effected by means of Weir two-stage steam-jet air-ejectors, and the condensate is handled by a Weir independent pump. The same makers supplied a cast-iron condensate well for each engine, as well as a pair of direct-acting boiler-feed pumps. Feed-water filtration is effected by a Weir filter. Two reversing engines have been provided by Messrs. Brown

FIGURE 3.—CHRISTIANSEN & MEYER ENGINE (FROM AFT).

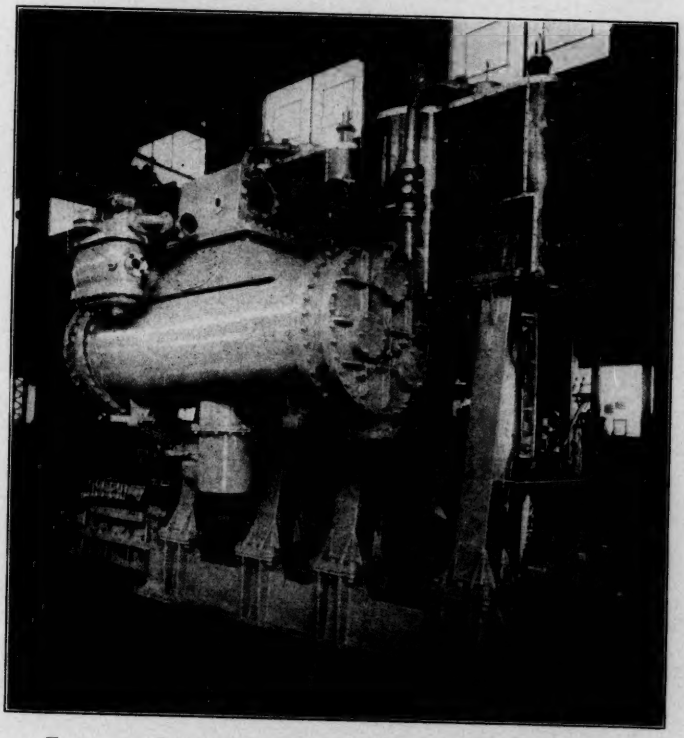


FIGURE 4.—CHRISTIANSEN & MEYER ENGINE (FROM FORWARD).

Cut-off 50% on all cylinders

Total I.H.P. = 1,218 Port engine		Total I.H.P. = 1,247 Starbd. engine
Steam press., forᵈ boiler	220	220
" " aft "	220	220
H.P. rec. forᵈ	205	205
" " aft.	205	205
Forᵈ L.P rec. Top = 75. Bottom	70	
Aft " " " = 75. "	70	
Vacuum	24½"	23"
Deg. superheat	425°F.	425°F
R.P.M.	144	144

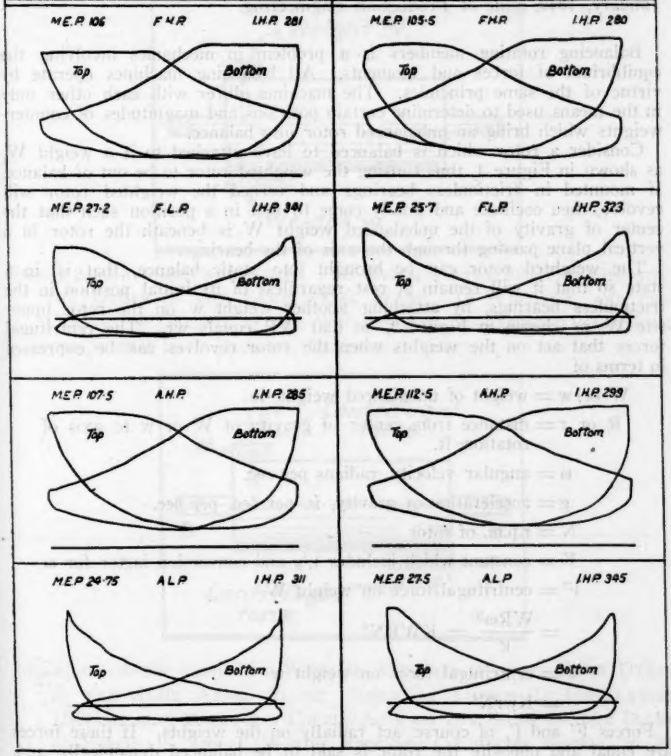


Fig. 2.—Indicator Diagrams.

Brothers & Co., Ltd., of Edinburgh. A multi-collar type of main thrust bearing is installed in connection with each engine, and oil fuel is handled by a Weir transfer pump.

The *Ernest Lapointe* entered service in the spring of 1941 in the St. Lawrence River, and, in company with other vessels of the Canadian Government Fleet, played a large part in opening the channel to Montreal at a very early date. This dual-purpose vessel, of a type which in her design necessarily presented many special problems, successfully performs her varied functions on dimensions giving a most economical unit, the ship reflecting great credit on all concerned in her evolution and construction.

DYNAMIC BALANCING.

Mr. F. L. Schwartz, of the University of Michigan, describes the theory and principles governing procedure in this short article reprinted from the January, 1942, issue of Production Engineering.

Balancing rotating members is a problem in mechanics involving the equilibrium of forces and moments. All balancing machines operate by virtue of the same principles. The machines differ with each other only in the means used to determine certain positions and magnitudes of counterweights which bring an unbalanced rotor into balance.

Consider a rotor which is balanced to have attached to it a weight W, as shown in Figure 1, thus causing the weighted rotor to be out of balance. If mounted in frictionless bearings and turned the weighted rotor will revolve, then oscillate and finally come to rest in a position such that the center of gravity of the unbalanced weight W is beneath the rotor in a vertical plane passing through the axis of the bearings.

The weighted rotor can be brought into static balance, that is. in a state so that it will remain at rest regardless of its initial position in the frictionless bearings, by attaching another weight w on the rotor opposite W, as shown in Figure 2, so that WR equals wr. The centrifugal forces that act on the weights when the rotor revolves can be expressed in terms of

W or w = weight of unbalanced weight, lb.

R or r = distance from center of gravity of W or w to axis of rotation, ft.

ω = angular velocity, radians per sec.

g = acceleration of gravity, ft. per sec. per sec.

N = r.p.m. of rotor

K = constant which includes $1/g$ and conversion factor for ω

F' = centrifugal force on weight W

$$= \frac{WR\omega^2}{g} = KWRN^2$$

f' = centrifugal force on weight w

$$= KwrN^2$$

Forces F' and f', of course, act radially on the weights. If these forces are equal and opposite the rotor is said to be balanced dynamically and, of course, the rotor will also be balanced statically.

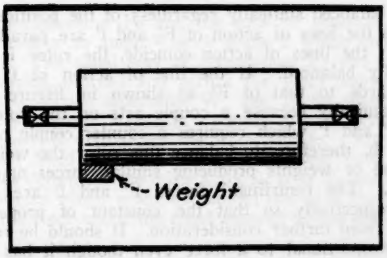


FIGURE 1.—BALANCED ROTOR MOUNTED IN FRICTIONLESS BEARINGS WITH A WEIGHT ATTACHED WHICH CAUSES ROTOR TO BE OUT OF BALANCE.

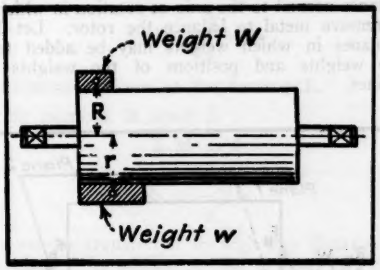


FIGURE 2.—BALANCED ROTOR WITH TWO WEIGHTS ATTACHED, ONE OPPOSITE THE OTHER IN THE SAME AXIAL PLANE. IF WR = wr, AND THE CENTERS OF GRAVITY OF THE WEIGHTS ARE DIAMETRICALLY OPPOSITE THE SYSTEM IS IN DYNAMIC BALANCE.

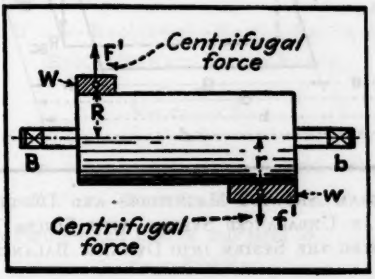


FIGURE 3.—ROTOR WITH TWO WEIGHTS ATTACHED OPPOSITE EACH OTHER IN THE SAME AXIAL PLANE. ROTOR AS SHOWN IS UNBALANCED DYNAMICALLY BECAUSE A COUPLE ACTS ON THE ROTOR IN THE PLANE OF FORCES F' AND f' WHICH REQUIRE A COUNTER COUPLE TO BE PRODUCED AT THE BEARINGS.

The rotor is balanced statically regardless of the position of W relative to w as long as the lines of action of F′ and f′ are parallel as illustrated in Figure 3. If the lines of action coincide, the rotor is dynamically as well as statically balanced. If the line of action of f′ is parallel but displaced sidewards to that of F′ as shown in Figure 3 the rotor is unbalanced dynamically because a couple acts on the rotor in the plane of the forces F′ and f′ which requires a counter couple produced by the bearings B and b, therefore, to balance this rotor the weights W and w must be removed or weights producing similar forces opposite F′ and f′ must be added. The centrifugal forces F′ and f′ are proportional to WR and wr respectively so that the constant of proportionality KN^2 may be dropped from further consideration. It should be remembered that WR or wr is proportional to a force even though it has the dimensions of a moment.

Considering a general case of balancing let a rotor be supported on bearings of a balancing machine at B and b, Figure 4. Let C and c contain two arbitrary planes normal to the axis of rotation in which it is practicable to place or to remove metal to balance the rotor. Let P and p contain two arbitrary planes in which weights may be added temporarily while determining the weights and positions of the weights to be added in the C and c planes.

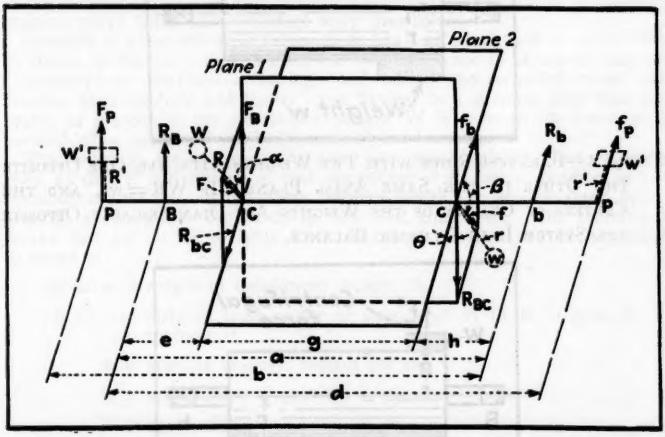


FIGURE 4.—DIAGRAM SHOWING MAGNITUDES AND DIRECTIONS OF FORCES ACTING IN AN UNBALANCED SYSTEM WITH FORCES THAT MUST BE ADDED TO BRING THE SYSTEM INTO DYNAMIC BALANCE.

It is the purpose of the balancing machine to determine a weight W′ at a radius R′ in plane P and a weight w′ at a radius r′ in plane p which will balance the rotor. $W'R' = F_P$ and $w'r' = f_P$ may be replaced by electrical means but essentially the forces F_P and f_P or their equivalent must be measured. The forces F_P and f_P will not necessarily lie in the same radial plane.

Let the plane containing F_p and the axis of rotation be plane 1 and assume that it makes an angle Θ with plane 2 which contains f_p and the axis of rotation. The usual way of determining F_p and f_p is to hold one support, say bearing b fixed and permit the other support B to vibrate in a given plane. Then determine W′ and R′ in plane P so that the support B does not vibrate. Then in a similar manner f_p may be determined by locking support B and permitting b to vibrate. An alternative is to keep one support fixed and the other one free and then invert the rotor in its bearings to determine the other force f_p after F_p has been determined. F_p and f_p are forces which when introduced one at a time produce balance of that end of the rotor about the fixed support at the far end of the rotor.

Taking moments M about b

$$\Sigma M = 0$$

$$(R_B \times a) - (F_p \times b) = 0$$

$$\text{or } R_B = \frac{b}{a} \times F_p$$

where R_B is an equivalent force at the bearing B.

Similarly, taking moments M about B

$$\Sigma M = 0$$

$$R_b = \frac{d}{a} \times f_p$$

The force R_B can be transferred through the distance e to C parallel to itself in the plane 1 by adding to the system the couple $R_{BC} \times g$ as shown in Figure 5 such that

$$R_{BC} \times g = R_B \times e$$

Then by taking moments M about c in plane 1 and using R_B reversed since it is to be the equilibrant of the new set of forces, the conditions of equilibrium are

$$\Sigma M = -R_B \times (e+g) + R_B \times g + R_{BC} \times g = 0$$

$$R_B \times e + R_B \times g = R_B \times g + R_{BC} \times g$$

$$R_{BC} = \frac{e}{g} \times R_B$$

and the algebraic sum of the vertical forces V equal zero or

$$\Sigma V = -R_B - R_{BC} + R_{BC} + R_B = 0$$

The force F_B in Figure 4 can then be expressed as

$$F_B = R_B + R_{BC}$$

Similarly, for plane 2 taking moments about C, as shown in Figure 6

$$R_{bc} = \frac{h}{g} \times R_b$$

or in Figure 4

$$f_b = R_b + R_{bc}$$

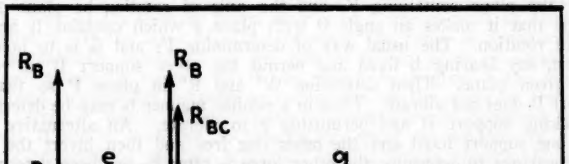


FIGURE 5.—METHOD OF TRANSFERRING PARALLEL TO ITSELF THE BEARING REACTION FORCE ACTING IN PLANE 1 BY INTRODUCING A NEW FORCE AND A COUPLE.

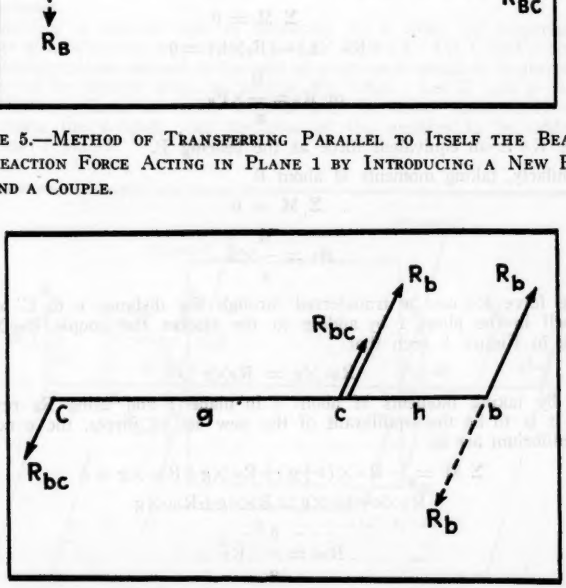


FIGURE 6.—METHOD OF TRANSFERRING PARALLEL TO ITSELF THE BEARING REACTION FORCE ACTING IN PLANE 2 BY INTRODUCING A NEW FORCE AND A COUPLE.

Now, as shown in Figure 4, add F_B and R_{bc} vectorially to get their resultant F and the angle α. The counterweight W at radius R is the required balancing weight in the C plane. WR must equal F and W must be located at an agle α to the plane 1. In like manner f is the vector sum of f_b and R_{BC} and is inclined at an angle β to the plane 2 as shown in the illustration.

If the rotor is mounted in a cradle and the supports of the cradle are placed in the correction planes C and c, distances e and h become zero and a equals g. Then it becomes unnecessary to transfer the forces

R_B and R_b to the planes C and c. This is the first simplification that has been introduced in the design of nearly all balancing machines. Some machines have one support fixed such as b placed in plane c and the other support free to move and then the force F_p is determined by trial and error on a compensating drum so that the free support does not move. Then the force f_p is found by inverting the rotor in its bearings and repeating the operation. Other machines have a drum which locates F_p automatically.

Another time-saving improvement is to be able to lock one support and permit the other one to be free and then by moving a lever unlock the locked support and fix the free support thus eliminating the necessity of reversing the rotor. Some machines measure a voltage which is proportional to the amplitude of vibration at the supports and thus obtain a reading proportional to F_p. By measuring the phase angle of the alternating voltage generated, the angle α is determined. A late type of balancing machine uses an electrical network to automatically locate the amount and position of the balancing weights. Electrical pickups measure the amplitudes at two supports and the electrical network performs the calculations thus giving direct and automatic readings for the position and amount of balancing weight to be added or removed.

Balancing machines which use compensating weights to locate the amount and position of balancing weights are usually made to hold the rotor in a cradle and use low balancing speeds. There is an advantage in using balancing speeds of the same order as the speed at which the part being balanced normally operates. In some rotors such as an armature of an electric motor there is a possibility of the parts (windings) shifting slightly when run at speeds higher than those used in the low speed balancing machines.

The latest type of balancing machine uses electric pickups which are inverted loud speakers at the bearings of the rotor being balanced. In this machine which is completely automatic the bearings are mounted on flexible

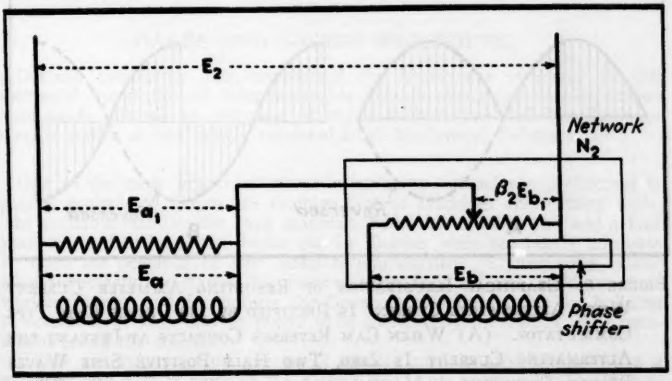


FIGURE 7.—SIMPLIFIED DIAGRAM OF AN ELECTRICAL SYSTEM USED ON BALANCING MACHINE FOR OBTAINING A RESULTANT VOLTAGE WHICH IS PROPORTIONAL TO THE CORRECTION WEIGHT WHICH MUST BE ADDED TO DYNAMICALLY BALANCE A ROTATING SYSTEM.

supports. The voltage generated at each bearing is proportional to the amount of vibration at the bearing and by an ingenious electrical network a resultant voltage is obtained which is proportional to the correction weight to be added. A simplified diagram is shown in Figure 7, of the electrical system. In this diagram, E_a is the voltage generated by the pickup at bearing A, and E_b is the voltage generated at bearing B. If the N_3 network is adjusted so that

$$E_{a1} = -\beta_2 E_{b1} \tag{1}$$

when an unbalance is set up by an unbalancing weight w_1 only, then

$$E_a + \beta_3 E_b = E_2 \tag{2}$$

Equation (1) is the defining equation for the network N_3 and is satisfied by adjusting the network N_2 during calibration of the balancing machine for a given setup. Equation (2) is the operating equation for the balancing machine and indicates that voltage E_3 which is proportional to and in fixed phase relation with w_2 equals E_a plus a proportion β_3 of E_b. These two voltages E_a and $\beta_2 E_b$ are placed in series. The network N_3 automatically performs the operation β_3 by shifting the phase and changing the amount of the voltage E_b to $\beta_3 E_b$. The voltage E_3 thus determines the correction weight w_3 to be added and furthermore E_2 has a fixed phase relation with the weight w_2 so that knowing this fixed phase relation, w_3 may be located. This is done by means of a stroboscope and suitable markings on the rotor.

By suitable switches a similar network N_1 for the other end of the rotor may be incorporated in the circuit and a voltage E_1 which determines correction weight w_1 may be determined. The rotor may be completely balanced with one run. It is not necessary to stop the rotor to reverse it or to reverse the fixity of one of the bearing supports. In this machine both flexible supports are free to vibrate at all times. Another advantage

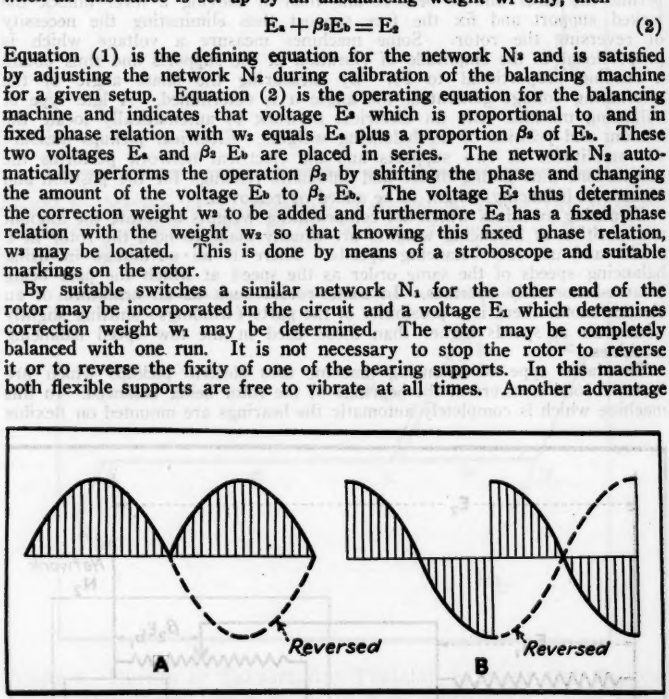


FIGURE 8.—GRAPHICAL ILLUSTRATION OF RESULTING AMMETER CURRENT WHEN ALTERNATING CURRENT IS RECTIFIED BY 180 DEGREE CAM TYPE COMMUTATOR. (A) WHEN CAM REVERSES CONTACTS AT INSTANT THE ALTERNATING CURRENT IS ZERO, TWO HALF POSITIVE SINE WAVES RESULT PRODUCING A MAXIMUM AMMETER READING. (B) WHEN CAM REVERSES THE POSITIONS OF CONTACTS AT THE INSTANT THE ALTERNATING CURRENT WAVE IS A MAXIMUM THE RESULTING AMMETER READING IS ZERO.

is that the rotor may be balanced in its own bearings, the bearings being supported on flexible supports. The necessary corrections for balancing may be obtained in twenty seconds.

Another type of balancing machine uses electric pickups at either end of a cradle holding the rotor, the cradle being pivoted at one of the correction planes. As the cradle vibrates horizontally about the pivot because of an unbalanced rotor, an alternating voltage is generated in the pickup at the opposite end of the cradle. The alternating current is rectified by a cam type commutator. The cam has two 180 degree dwells and two sets of contacts 180 degrees apart are operated by the cam. The cam turns with the rotor being balanced. As the cam rotates it opens and closes the contacts each 180 degrees thus reversing the alternating current for 180 degrees of each cycle. If the cam is reversing the positions of the contacts at the instant the alternating current is zero two half positive sine waves result as in Figure 8 (A) and a d.c. microammeter will read a maximum. If the cam is reversing the position of the contacts at the instant the alternating current wave is a maximum, that is, 90 degrees later, the resulting ammeter current will be zero, Figure 8 (B). For any other position of the cam an intermediate value of current is read on the ammeter.

The location of the contacts relative to the cam may be shifted and as they are rotated a graduated scale of angles revolves with the contacts. Thus by moving the contacts until a zero reading is obtained the angle of unbalance can be read on the angle scale under a properly placed index. Then by moving the contacts 90 degrees a maximum reading is obtained and the magnitude of the ammeter current is a measure of the amount of unbalance in the unpivoted correction plane. By pivoting the other correction plane and allowing the first correction plane to be free and repeating the procedure the other correction weight may be determined. It should be recalled that in both types of balancing machines using electrical pickups two angles and two weights must be determined.

GAGES AND GAGING PROCEDURE.

Defense production has emphasized the importance of gages in the successful application of interchangeable manufacturing methods to armament work. Mr. G. H. Simpson, of the Greenfield Tap and Die Corporation, is author of this article reprinted from Machinery, February, 1942.

One of the most important items in carrying out defense production is gaging equipment. Gages are as important as machines and cutting tools. The available facilities for gage manufacture in this country two and a half years ago, when hostilities broke out in Europe, were not nearly adequate to meet the demands of war material manufacture. Consequently, many gage manufacturers started to increase their facilities and build up their working forces; and, in addition, the Government arranged for the building of several large gage-making plants to be operated by the leading gage manufacturers of the country.

There are two principal groups of devices used in ascertaining when a manufactured part is made to the correct size. One group includes measuring devices; the other, gages.

A measuring device is provided with a graduated scale, and the dimension to be measured is compared directly with the scale. This group includes the ordinary machinist's scale, micrometers, vernier calipers, and measuring machines.

Gages are not, strictly speaking, measuring devices. Their function is simply to compare the dimension of the product with a predetermined dimension of the gage. Limit gages establish the maximum and minimum limits of the product within the specified tolerance. The work to be gaged must not be larger than the maximum size nor smaller than the minimum size specified for the product.

Definition of Terms.

Before proceeding further, the terms used in connection with gaging in interchangeable manufacturing should be clearly defined. Many of the terms used in gaging procedure are loosely employed, and much confusion is caused by a misunderstanding of these terms. Often serious errors are made in manufacturing simply because the terms are differently interpreted. The four most important terms are tolerance, limit, clearance, and allowance.

Tolerance—Tolerance is the permissible variation in a given dimension. The tolerance may be applied either all above or all below, or split part above and part below the basic dimension. For example, a shaft may be made to any one of the following limits: 1.500—1.496; or 1.504—1.500; or 1.502—1.498. In each case the shaft has different limits, but the tolerance remains the same, namely 0.004 inch.

Limit—Limits are the maximum and minimum dimensions of a part. In the previous example, respectively, the maximum limit would be 1.500 inches and the minimum limit 1.496 inches; or maximum, 1.504 inches and minimum 1.500 inches; or maximum, 1.502 and minimum 1.498. While the limits are all different, the tolerance, as stated before remains 0.004 inch in each case.

Clearance—Clearance is the space provided between two mating parts when assembled. The purpose of the clearance may be to prevent interference or to produce a certain freedom of fit.

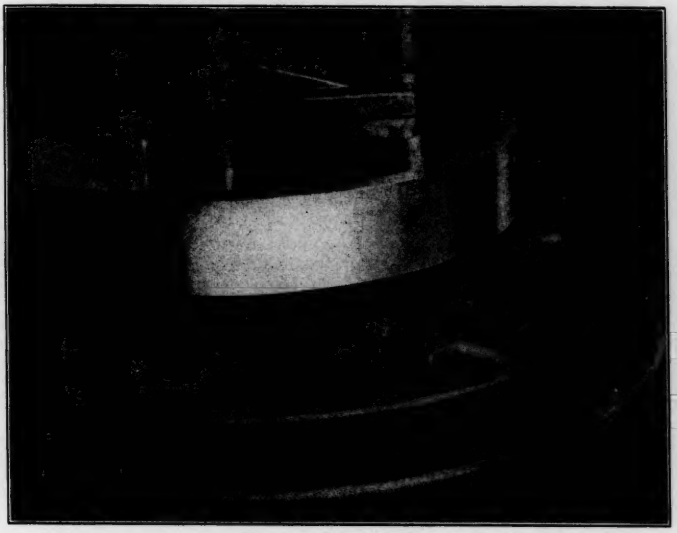
Allowance—Allowance is the intentional difference in size between mating parts. It may be defined as the minimum clearance or the maximum interference that is intended between mating parts. It may provide clearance or interference as desired. When there is clearance, the allowance is called positive; when there is interference, the allowance is called negative.

There are many other terms used that are simply different names for the terms just defined—such as working tolerance, permissible tolerance, necessary tolerance, high limit, low limit, working clearance, and working allowance. The use of these terms causes confusion and should, therefore, be discouraged. Such an expression, for example, as "a limit of 0.001 inch" is objectionable because it is both incorrect and indefinite. It is incorrect because tolerance is meant instead of limit; and it is indefinite because it gives no indication of whether the tolerance is above or below the basic dimension, or partly above and partly below. The expression, for example, may mean a tolerance of 0.001 inch over the basic dimension or a tolerance of 0.001 inch below the basic dimension; it may mean a tolerance of 0.0005 inch both above and below the basic size; or it may mean 0.001 inch both above and below the basic size.

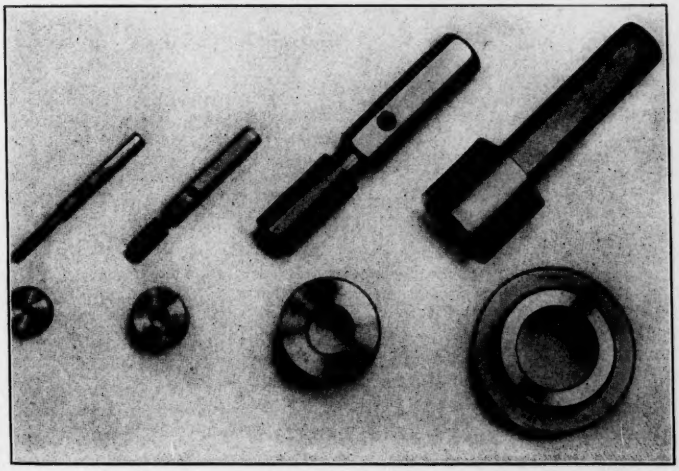
The words tolerance, limit, clearance, and allowance should be used in accordance with accepted practice, so that there can be no possible doubt as to their meaning.

Gaging in Interchangeable Manufacturing.

Since gages in general compare only one or, at best, a few predetermined dimensions, they are used principally in interchangeable manufacturing—that



MECHANICAL LAPPING OF CYLINDRICAL PLUG GAGES.



EXAMPLES OF STANDARD DESIGNS OF CYLINDRICAL PLUG AND RING GAGES.

is, when a number of similar parts are to be made. Gaging methods and interchangeable manufacturing procedure are so closely allied that it is impossible to discuss one without the other. The main object in the introduction of interchangeable manufacturing was to decrease costs by standardizing the manufacturing operations and to reduce the time required for assembling a machine or mechanism.

An additional advantage, however, is thereby gained—that of a complete interchange of like parts in manufactured articles. In many cases, the latter advantage has become as important as the reduction in assembling costs. In much war material, this interchange of parts is of prime importance, as, for example, in the manufacture of rifles and heavy ordnance, it permits damaged parts to be replaced quickly without fitting. On the other hand, in shell or projectile work, interchangeable manufacturing methods are used largely for the sake of facilitating assembly, because, when once assembled, there is little likelihood that the parts will be interchanged with other parts.

One of the most obvious examples of the need for interchangeability arises when one part of a device is made in one shop and other parts are made in another shop. It is clear that "accuracy of dimension" is then necessary, in order that these parts may be properly assembled without additional cost in fitting them together.

When so much of the war materials are subcontracted as is now the case, the necessity of interchangeability and, hence, careful and accurate gaging methods becomes of supreme importance. If two shops work independently, they are likely to use different locating points in taking measurements, different tooling equipment, different machining methods, and different gages and gaging methods. It is of importance that there be thorough coordination between plants working on the same contract in order to insure complete interchangeability. In other words, the gaging equipment and gaging methods must be alike or based upon the same principles. The details of the machining methods and, to some extent, the tooling equipment may vary, but the gages ought to be of identical design; otherwise, it is almost certain that the parts will not interchange properly.

Classification of Gages According to Their Use.

In general, three different kinds of gages are employed in an industrial plant, according to their use in the shop and inspection departments—working gages, inspection gages, and reference gages. The latter are sometimes known as checking gages or check gages.

As is evident from the name, working gages are used by the machinist or machine operator at the bench or machine at which he is working, and are used for gaging the product during an operation. Inspection gages, again, are used by the inspectors in checking the product to determine that it meets the requirements. Finally, reference gages are used for testing or checking the inspection and working gages from time to time, to make sure that they have not, through wear, become inaccurate for the purpose for which they are intended. In addition, there are master gages that may be used occasionally as an ultimate check on the reference gages.

Tolerances on the Gages Themselves.

It is evident, of course, that the gages themselves can be accurate only within a certain tolerance, as it would be impracticable to make gages that had no measurable error whatsoever. The gage tolerance depends to a considerable extent upon the size of the gage; and in thread gages, upon the pitch.

There are several standardized gagemaker's tolerances applicable to the gages themselves, of different degrees of accuracy. A gage with a certain tolerance should, of course, be selected with relation to the tolerance of the product. It is obvious that there can be no single standard with regard to the tolerance on the working and inspection gages for specified work in interchangeable manufacturing, as these tolerances must depend upon the amount of tolerance allowed in the product being gaged.

For example, if the tolerance on the work or product is 0.010 inch, it is evident that a gage should not be made to as small a gagemaker's tolerance as would be the case if the tolerance on the work or product were only 0.001 inch. This is the reason why gage manufacturers make some of their standard commercial gages with as many as four different classes of tolerances, so that they may suit the work to be inspected. These four classes fit the majority of cases met with in interchangeable manufacture.

Within certain limitations, it has been found good practice to allow a tolerance on the gage amounting to 10 per cent of the tolerance on the product. For example, if the tolerance on the product were 0.003 inch, then, in general, the tolerance on the maximum gage would be 0.0003 inch, and applied in a direction below the maximum size of the work; the tolerance on the minimum gage would be 0.0003 inch, and applied in a direction above the minimum size of the work.

Use of Working and Inspection Gages.

It is the general practice in interchangeable manufacturing to provide working gages for every operation and to furnish each operator with his own working gages.

In designing a gaging system with working, inspection, and reference gages, it is common practice to vary the limits on the gages intended for each purpose. For example, the working gages would not necessarily be made to the limits indicated on the drawing or to the size to which the inspection gages are made. There may be a conflict in the acceptance and rejection of the product when gaged by working and inspection gages made to the same limits. This is due to the manufacturing tolerance on the gages themselves. A product made close to either maximum or minimum limit could be accepted by the working gage and rejected by the inspection gage, due to slight variations in the gage dimensions or wear. To overcome this difficulty, the product tolerance as determined by the working gages may be curtailed sufficiently to allow the product passed by the working gages to be accepted by the inspection gages, regardless of the gagemaker's tolerance.

When the inspection and working gages are alike, disputes often arise as to whether the inspection department is justified in rejecting certain work. Curtailing of the product tolerance by the working gages is a question to be settled by the gage user. It is his responsibility to determine if the extra cost of manufacture entailed by curtailment of the product tolerance by the working gages is compensated for by the freedom from conflict between inspection and working gages.

Inspection gages are usually made so that the largest maximum gage and the smallest minimum gage are equivalent to the maximum and minimum product limits, respectively. As a rule, it is not common practice to inspect the work after every individual operation, but, in general, inspection takes place when the parts leave one department to pass into another, or before they pass from one important operation to another.

Reference and master gages are maintained for the purpose of checking the dimensions of the inspection and working gages. When plug gages are to be used as reference gages, they are generally kept exclusively for that purpose, so that they will not be subject to undue wear.

Tolerances in Interchangeable Manufacturing.

In any discussion of gages and gaging procedure, the matter of tolerances on the work is obviously the first consideration. In spite of all that has been written about tolerances and all the research work that has been done, the determination of suitable tolerances is still a puzzle to many designers. If this subject were thoroughly understood, much time and expense could be saved in the manufacture of war materials, in the making of tools and gages for their manufacture, and in avoiding controversies with regard to acceptable material. This, of course, also applies in the manufacture of products for peacetime purposes; but, as a rule, such manufacture is directly in the hands of manufacturing executives who are responsible for profitable results and, therefore, "impractical tolerances" are not so often encountered.

Many designers seem to believe that tolerance should be established with reference to the minimum tolerance that can be obtained by modern machining methods. Instead, the tolerance should be established with reference to the maximum tolerance permissible in the component parts of a mechanism without interfering with its proper purpose or action. If this principle is kept in mind by designers, the expense of manufacture can be greatly reduced. It is of especial importance at present, in connection with the manufacture of ordnance and other classes of war materials, because, if the tolerances are as liberal as possible, the manufacture of war materials can be greatly speeded up, and costs can be reduced as well.

It should also be remembered that the tolerance on the work will always be less than the tolerance on the drawing, because the dimensions on the drawings are the maximum and the minimum limits of the inspection gages. Hence, it is evident that with gages made to these dimensions, and with reasonable gage tolerances applied inside the product limits, the product that passes inspection must have tolerances that are less than those indicated by the dimensions on the drawing, especially since most work comes well within the limits of the gages. This means that the tolerance on the drawing should always be made liberal enough to allow for this necessarily smaller tolerance in the work actually produced.

Cylindrical Ring Gages.

Dealing now specifically with different types of gages, the first type to which attention will be called is the cylindrical ring gage. These gages are furnished to the trade in four different groups, according to finish and accuracy, designated as Class X, Class Y, Class Z, and Class ZZ. The tolerances corresponding to given size ranges and classes are listed in Table 1.

Table 1. Tolerances for Cylindrical Ring Gages.

Size Range		Class X	Class Y	Class Z	Class ZZ
Above	To and Including				
0.029	0.825	0.00004	0.00007	0.00010	0.00020
0.825	1.510	0.00006	0.00009	0.00012	0.00024
1.510	2.510	0.00008	0.00012	0.00016	0.00032
2.510	4.510	0.00010	0.00015	0.00020	0.00040
4.510	6.510	0.00013	0.00019	0.00025	0.00050
6.510	9.010	0.00016	0.00024	0.00032	0.00064
9.010	12.010	0.00020	0.00030	0.00040	0.00080

The life of gages is greatly increased by lapping the contact surface. There is more bearing area on a lapped surface than on a ground surface, since the ridges are greatly reduced by the lapping process.

Class X plain ring gages are precision-lapped to very close tolerances and are used principally as master and reference gages. They are not used as working gages except when especially close tolerances are required.

Class Y plain ring gages, which are also precision-lapped, are used as working gages and inspection gages of accurately ground parts.

Class Z plain ring gages are used when extreme accuracy is not essential and when the working tolerances are fairly liberal. These gages have a ground and lapped finish. This is the regular commercial type of ring gage that manufacturers furnish unless the requirements call for greater accuracy. Class ZZ plain ring gages are ground, but not lapped. They are the most inexpensive ring gages available, and are used when the number of pieces to be gaged is comparatively small and when tolerances are liberal.

Cylindrical Plug Gages.

Cylinderical plug gages are made in four classes, similar to ring gages. The tolerances are the same except that an XX tolerance is added and the ZZ tolerance is eliminated. The four classes of plug gages are designated XX, X, Y, and Z. The tolerances for these gages are given in Table 2.

Table 2. Tolerances for Cylindrical Plug Gages.

Size Range		Class XX	Class X	Class Y	Class Z
Above	To and Including				
0.029	0.825	0.00002	0.00004	0.00007	0.00010
0.825	1.510	0.00003	0.00006	0.00009	0.00012
1.510	2.510	0.00004	0.00008	0.00012	0.00016
2.510	4.510	0.00005	0.00010	0.00015	0.00020
4.510	6.510	0.000065	0.00013	0.00019	0.00025
6.510	9.010	0.00008	0.00016	0.00024	0.00032
9.010	12.010	0.00010	0.00020	0.00030	0.00040

Class XX plug gages are precision-lapped to very close tolerances, and are used principally for master gages, master disks, and setting gages.

Class X plug gages are also precision-lapped to close tolerances. They are used for some types of master and inspection gages, and for working gages when the tolerances are especially close and when the highest grade of precision in the work is required.

Class Y plug gages are lapped to slightly larger tolerances than the preceding classes, and are intended to be used as working gages.

Class Z plug gages have what is known as a commercial finish—that is, they are ground and polished, but not lapped. They are used as working gages when the tolerances are liberal and the quantities of pieces to be gaged are small.

Master disks or setting gages designed for checking and setting snap gages, comparators, and micrometers are regularly made with tolerances corresponding to the Class XX, Class X, and Class Y tolerances given in Table 2.

Adjustable-Limit Snap Gages.

Among the most generally used working gages are limit snap gages. These gages are designed for quick and accurate inspection of duplicate parts. They are made with two sets of anvils or measuring points, the outer anvils being set to the maximum size and the inner anvils to the minimum size of the work, so that with one quick motion on the part of the operator or inspector the gage will show whether or not the work is made to the prescribed limits.

The contact anvils of adjustable snap gages are made from hardened tool steel, ground and lapped. They are held in place by a locking screw. Each movable anvil can be independently adjusted. Periodical inspection adjustments and corrections must be provided for, since the anvils will become worn through use. Setting plugs or gage-blocks are generally used for adjusting and setting snap gages.

The foregoing principles of gaging practice apply to almost any gaging problem. There are, of course, specialized applications of these principles, but basically, the results are obtained by using the same set of rules. We have dealt principally with external and internal plain members. While these principles apply also to gages for threaded products, the gaging problem becomes more involved—so much so that threaded gages will be handled as a separate subject in an article which will appear in a coming number of Machinery.

SURVEY OF WELDING AND CUTTING IN SHIP CONSTRUCTION.

Special details of automatic and mechanized procedures are described by F. G. Outcalt and J. M. Keir in this paper presented at the Annual Meeting of the American Welding Society, held in Philadelphia during October, 1941. Their paper was published in the January, 1942, Journal of the Society.

Thirty thousand men will be engaged in welding and cutting in our country's shipyards this year according to recent estimates. If we assume that 24,000 of these men will be employed as welding operators and that each will deposit metal at an average rate of 20 pounds per shift, the quantity of metal deposited daily adds up to some 480,000 pounds. In thinking of such numbers of men and the dependence which the shipbuilding industry places upon them and upon the welded joints they produce, we cannot help remembering that as recently as 1935, many a shipbuilder mistrusted welding as a means of joining hull plating and other essential structural parts of a ship, and would have none of it.

Although a few nearly all-welded ships were built prior to 1936, the strongest real impetus to the welding of self-propelled ocean-going vessels was provided that year when the Sun Shipbuilding and Dry Dock Company built the virtually all-welded 521-foot, 18,500-ton tanker *J. W. Van Dyke* for the Atlantic Refining Company. An important feature of this construction was the use for the first time anywhere in shipbuilding of the then new Unionmelt automatic electric welding process.

Although the adoption of welding eliminated much of the layout work formerly required in the shipyard mold loft and greatly simplified the preparation of steel for the ship, the cutting of plate edges for welding is as important as proper shearing and punching for riveted construction.

Accurate preparation is necessary not only for structural reasons but for economic reasons. Lap joints can, of course, be used without accurate sizing of plate, but welded lap joints are uneconomical in plate, add useless weight to the ship, increase welding costs and complicate the details of construction. They are seldom used except when welding is applied as the method of joining on a structure that was originally designed to be riveted.

Welded construction, therefore, led to a careful consideration of plate-edge cutting; and since plate planers are costly to install and cannot be quickly obtained, attention naturally focused on flame-cutting equipment for cutting and beveling plate edges. The advantages of flame cutting for plate-edge preparation over planing, particularly at the present time of great shipbuilding activities can therefore be summarized as follows:

1. High speed of production.
2. Availability of equipment.
3. Low cost of equipment.
4. Low cost of power.
5. Low investment charges on equipment since major operating charges are for labor and consumable materials used only during production.

The cutting flames impose no external loads on the plate, and therefore heavy holding clamps, large tool-driving motors and massive installation foundations are not required. The hand-operated cutting blowpipe cannot be satisfactorily used for any but the shortest seams, since manual guiding causes irregular edges and bevels. Though such irregularly fitted edges can be welded, the sacrifices in welding speed and the cost of extra weld metal and labor required more than outweigh the apparent convenience of manual torch cutting. Much of the plate preparation for welding is now done with blowpipes mounted on small, portable, motor-driven carriages which travel in straight or curved paths on portable track or directly on the plate.

Figure 1 shows one unit which can be guided by track or can be accurately steered by the operator to make cuts almost equal to those obtainable with track guidance.

Figure 2 shows another type of carriage-mounted blowpipe unit which is generally used on track.

Many of the early types of these machines carrying one blowpipe are still in use for cutting plain square edges or single-beveled edges, and are sometimes used for cutting more complicated edge preparations by means of two or three passes of the single blowpipe. However, accuracy is difficult to obtain in this manner of multipass cutting because the tendency of each successive heating and cooling to warp the plate is cumulative, and compensation or correction is practically impossible.

A more advanced procedure of plate-edge preparation involves the use of two or three blowpipes or specially connected cutting nozzles so adjusted that the two or three surfaces are cut during one passage of the machine. The most complicated edge preparation of any commonly used for welding is the double-bevel with unbeveled root face. The sequence of cuts for this kind of edge preparation made during one pass of the machine having three closely spaced cutting nozzles is illustrated in Figure 3. This operation is more economical of gases than the making of three similar but separate cuts in three passes, and the total heat effect tending to distort the plate is but little greater than the heat effect of a single cut.

If bevels are to be cut with their top and bottom edges truly straight, the ends of the blowpipe nozzles must travel at exactly uniform distances from the plate surfaces as well as in a plane perpendicular to the plate and parallel with the finished edge. A blowpipe rigidly connected to a carriage

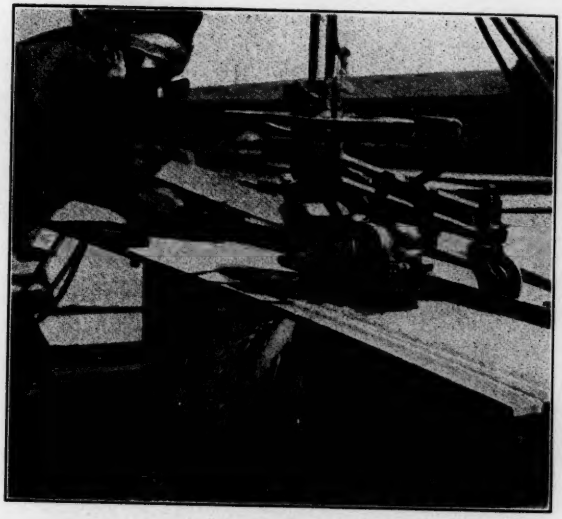
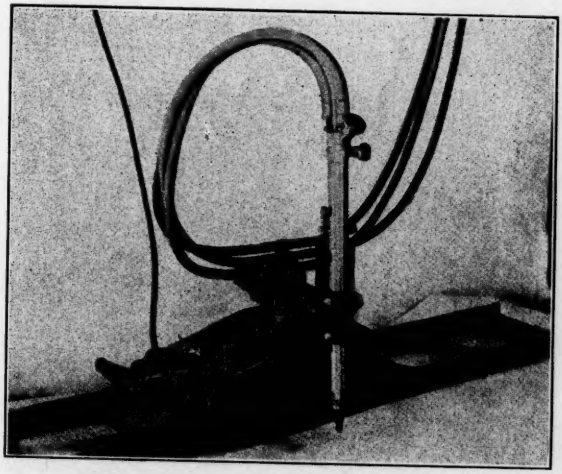


FIGURE 1.



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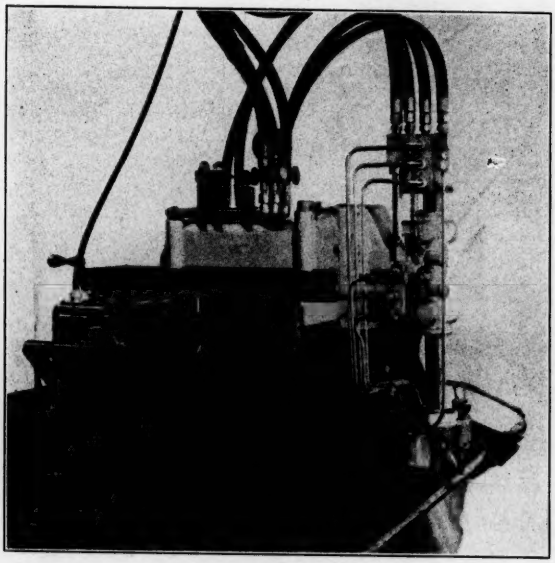

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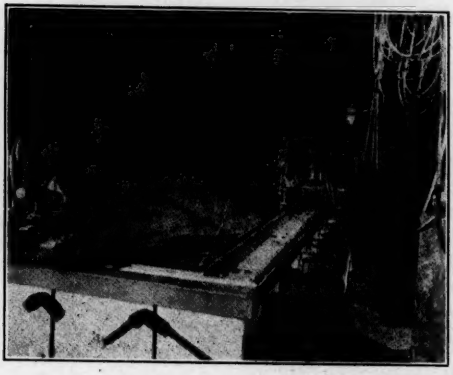

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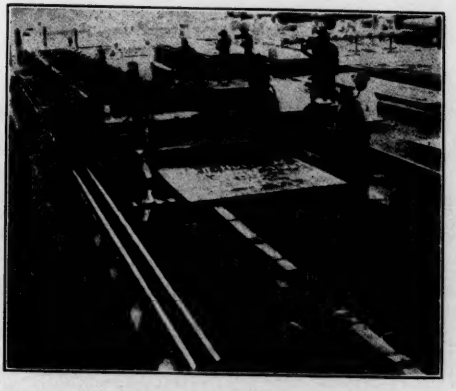

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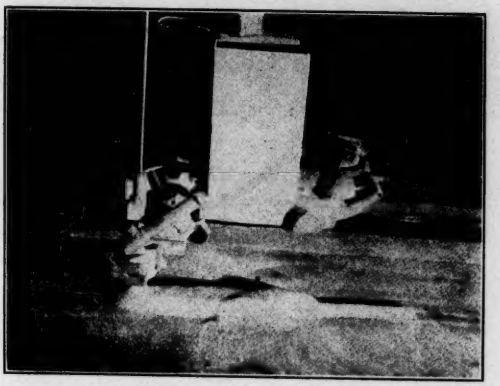

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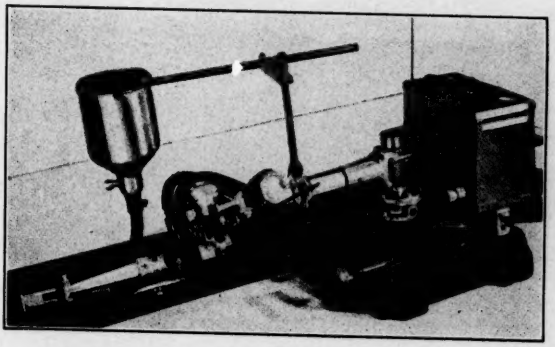

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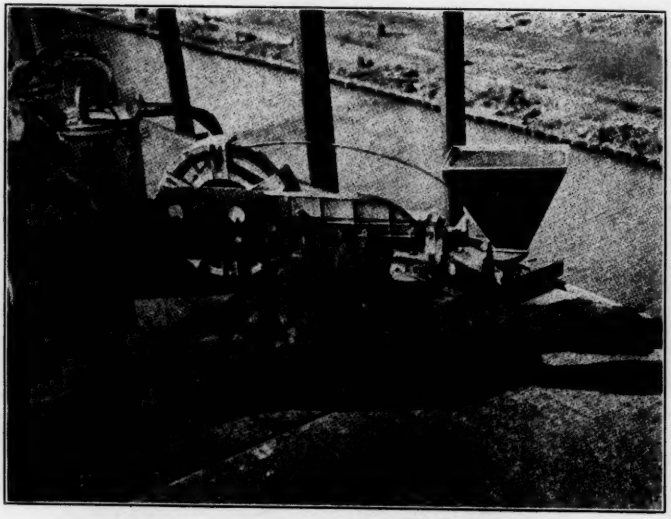

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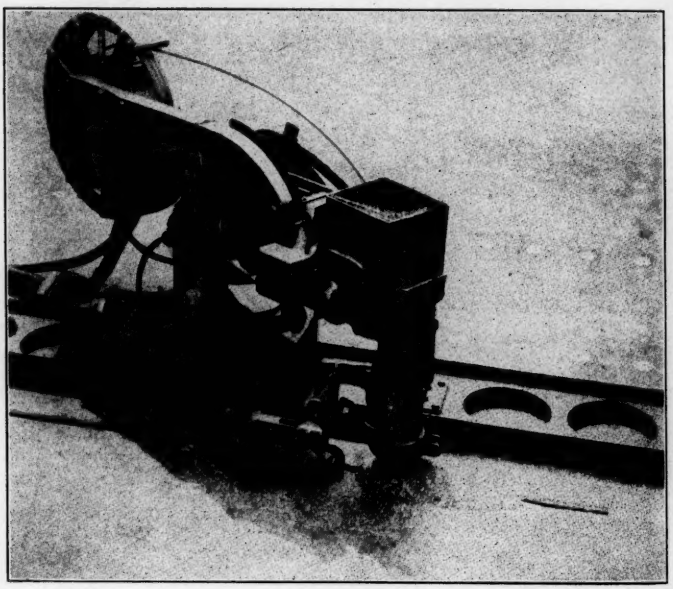

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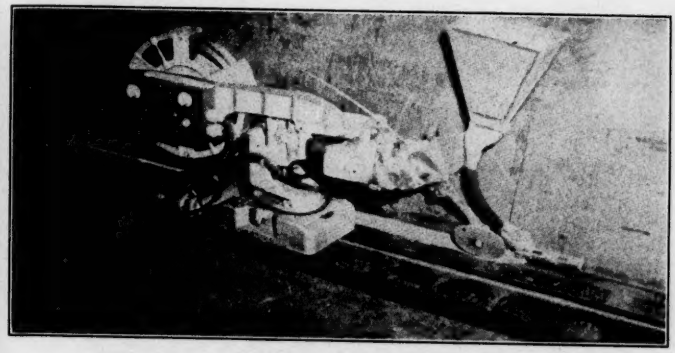

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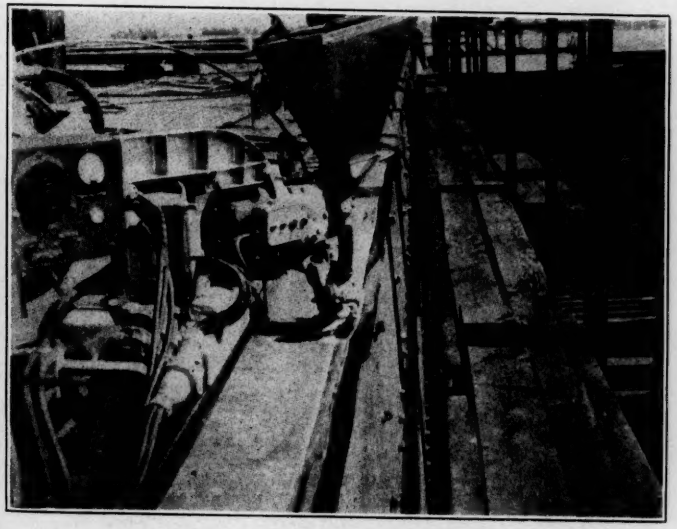

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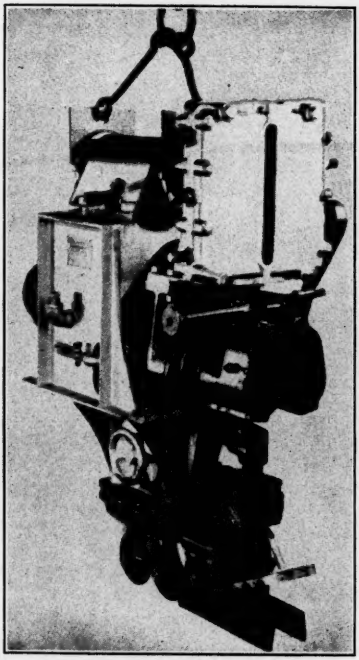

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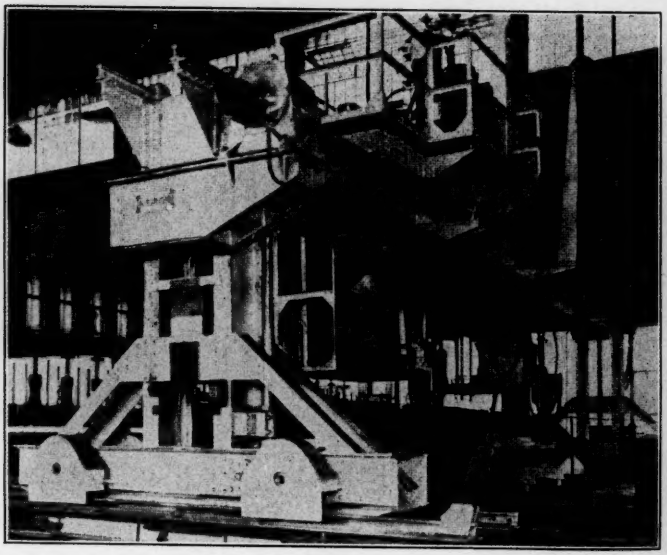

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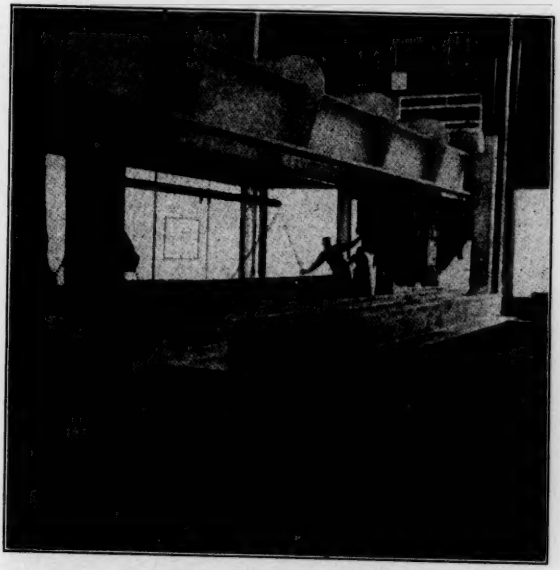

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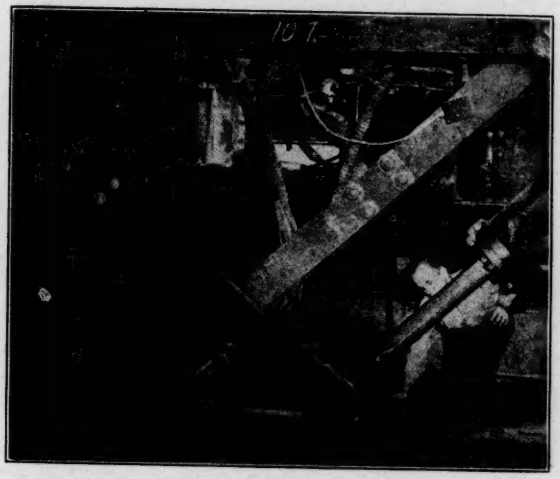

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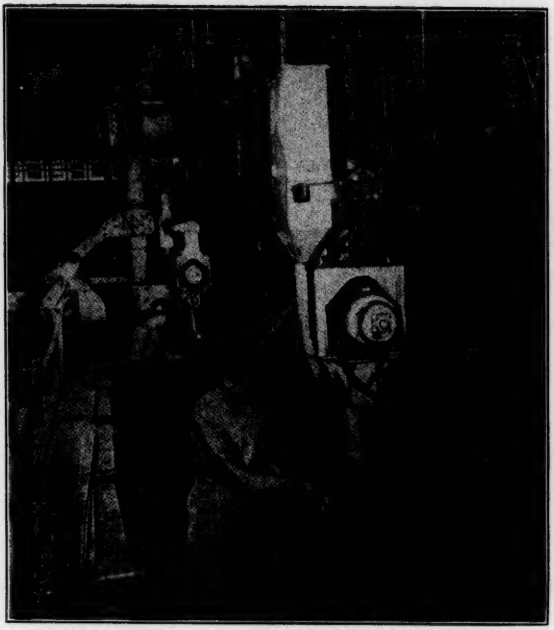

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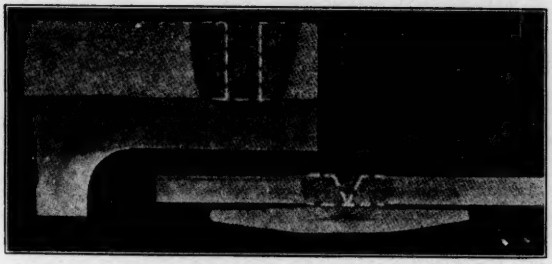

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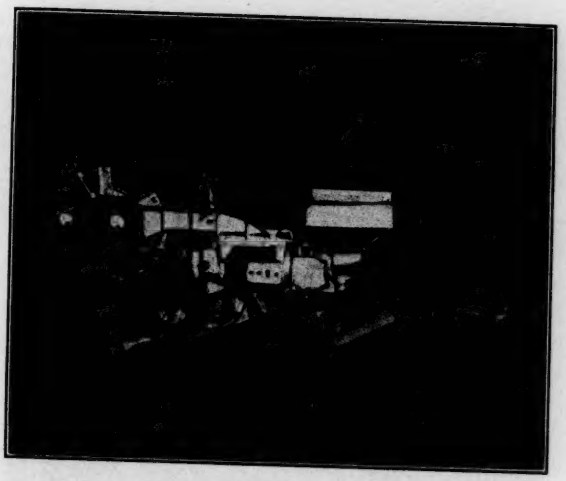

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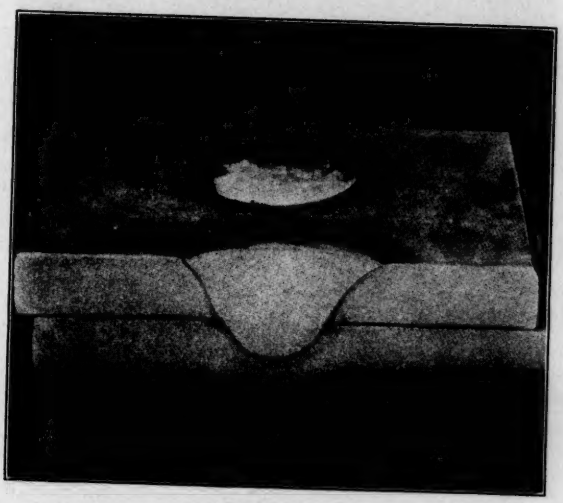

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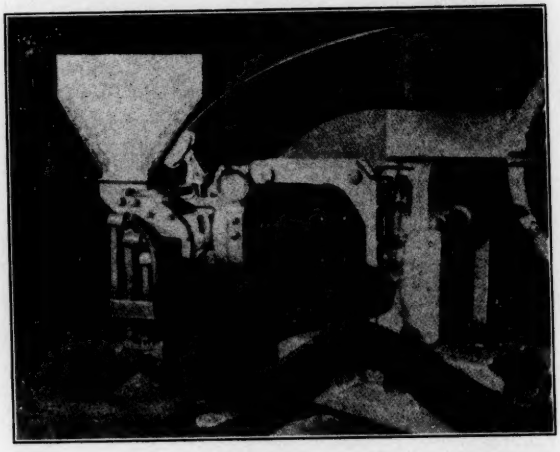

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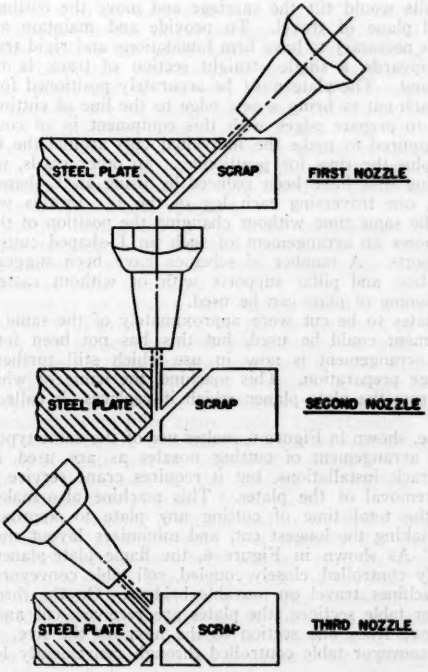


FIGURE 3.

traveling on a straight track cannot properly bevel anything but a perfectly flat plate. The heavy machine tool plate planer is designed to hold the plate firmly in a flat position, but since one of the desirable advantages of flame cutting is the lightness of the equipment, it proved easier to arrange for the blowpipes to rise and fall so that the distance between nozzles and plate surface would remain constant at all times, even when cutting a wavy plate.

An example of this type of cutting machine is shown in Figure 4. The cutting nozzles are atached to the lower end of the vertical shaft which is free to move up and down in accurately fitting roller bearings. The weight of the floating assembly is supported on a wheel riding directly on the plate surface adjacent to the cut. Depth of bevel and contour of cut on the plate edge are always uniform in relation to the surface on which this supporting wheel rides.

When long cuts are to be made with this type of equipment, it is essential that the track on which the blowpipe carriage operates be straight and level. Obviously, straight cuts cannot be made from a track that is less than straight, and since the machine is designed for cutting plate at a position below the level of the track, any variations in the relative elevation

of the two rails would tilt the carriage and move the cutting nozzles out of the desired plane of travel. To provide and maintain accurate track alignment, it is necessary to have firm foundations and rigid track mounting.

In some shipyards, a single straight section of track is installed on a permanent mount. The plate must be accurately positioned for cutting and turned after each cut to bring a new edge to the line of cutting. The total time required to prepare edges with this equipment is, of course, the sum of the time required to make the individual cuts around the full periphery of the plate, plus the time for positioning. In other yards, plate handling time and cutting time have been reduced by using an L-shaped track with two machines, one traversing each leg of the L. In this way, two cuts are made at the same time without changing the position of the plate.

Figure 5 shows an arrangement of such an L-shaped cutting track and the plate supports. A number of schemes have been suggested for supporting the plate, and pillar supports with or without casters to permit the easy positioning of plate can be used.

If all the plates to be cut were approximately of the same size, a four-track arrangement could be used, but this has not been found practical and a better arrangement is now in use which still further mechanizes flame plate-edge preparation. This machine, the name of which has been partly taken from the plate planer which it replaces, is called the "Flame Planer."

This machine, shown in Figure 6, makes use of the same type of carriages and the same arrangement of cutting nozzles as are used in the single track and L-track installations, but it requires crane service only for the delivery and removal of the plates. This machine also makes possible a reduction of the total time of cutting any plate to approximately that required for making the longest cut, and minimizes layout measuring and manual labor. As shown in Figure 6, the flame plate-planer consists of three separately controlled, closely coupled, roll table conveyors over which the cutting machines travel on movable bridges. On the three separately controlled roller table sections, the plates are received, cut and discharged. The plates move from one section to the next on the live, motor-driven rollers of the conveyor table controlled through conveniently located push-buttons.

At the cutting section, mechanical means, controlled at a central point, are provided for aligning the plate and holding it in position during the cutting operation. At both sides of the cutting bed are accurately positioned rails on which operate the movable bridges carrying the cutting equipment. For the simultaneous cutting of four edges of a plate, three bridges are provided.

The middle one of the three is electrically driven by a variable speed motor and gear reduction assembly, and carries two cutting units which make the longitudinal edge preparations and are easily adjustable to any position on the span across the roll table by means of a crank-operated feed screw. Floating mountings for the cutting heads, similar to those used in carriages previously described, are also used on these units so that the cuts will follow any waves in the plate.

The two end bridges carry the mechanism for transverse cutting of the plate. These end bridges are not motor driven but are provided with ball-bearing wheels for easy movement to any desired position along the main side rails, and can be quickly locked securely in place. On each of these bridges is mounted a standard motor-driven carriage like those pictured in Figure 4. Any of these units can be fitted with nozzle blocks carrying one, two or three nozzles for cutting a straight, square edge, a single bevel, a single bevel with unbeveled root face, a double bevel

or a double bevel with an unbeveled root face. The desired edge contour is, of course, finished in one single passage of the group of cutting flames along the plate. Since the adjustment of all the moving parts of the machine can be accurately maintained or quickly duplicated, a number of exactly similar plates can be cut very rapidly. Furthermore, the adjustments of the machine are so easily made that little time is required even if each plate is of different dimensions. Plates with curved edges and plates of irregular shape can also be cut by means of special attachments for the machine or by manual operation of the positioning controls.

Table 1 presents some production data based on the actual operation of this machine in a West Coast shipyard.

It is noteworthy that even for the most complicated double-vee- and square-root-face preparation of one-inch-thick plate, the time required for complete preparation of all edges of a rectangular piece is only one minute per foot of longest plate dimension.

The development of an accurate and rapid method of plate-edge preparation was fostered to a great extent by the development of rapid methods of welding and the consequent need for accuracy in plate alignment for butt-joint assemblies. It was not until the need for this alignment accuracy for automatic electric welding focused attention on edge preparation that the great advantages of accurate and uniform fitting of plate edges for manual arc welding were fully appreciated. Unfortunately, there are still many shipyard men who are unwilling to insist on careful edge preparation because they think costs will be increased. Actually the net total cost is usually decreased because of the savings in welding expense made possible by the elimination of poorly fitted joints.

Manual electric arc welding is the method by which the largest proportion of all ship welding is accomplished. It is virtually the only method used for welding vertical seams or where welding must be done "overhead" on the underside of a seam. For much of the "downhand" welding, where weld metal is deposited in seams on a virtually horizontal surface, manual arc welding is also used, particularly where the seams are short, are difficult to reach, or are in relatively thin material which can be welded completely in one or two passes. Much of the downhand arc welding is done with electrodes developed during the past few years which can be used with higher currents than the previously used electrodes. With these so-calld "hot" electrodes, metal can be deposited at high rates without as great losses of electrode in spatter and vaporization as would occur if high currents are used with ordinary electrodes. Current densities as high as 9000 amperes per square inch are recommended for these electrodes instead of the practical limit of approximately 6000 amperes per square inch for the "all position" "cold" electrodes.

This tendency toward more widespread use of the high-current electrodes has caused a decided trend toward higher capacity welding units such as the 400- and 600-ampere, single operator, DC generators, the 500- and 750-ampere AC. transformers and the larger multiple-operator units. Multiple-operator units are generally used to supply current to a greater number of operators than would be indicated from the rating of the equipment. Such apparent overloading has developed from experience which shows that because of the diverse activities of a number of operators, only a few are drawing their maximum required current at one time. Sometimes as many as 100 operators can be served by a machine of 5000-ampere capacity, even though each operator may sometimes use 200 or 300 amperes while actually welding.

Of the estimated 24,000 welding operators employed by the fifty or so Navy and private yards on the Coasts and Great Lakes, about 1000 to 1500

Time and Gas Consumption and Production Data

Plate Thickness, In.	Type of Edge Preparation	Approximate Time and Consumption of Gases per 10 Linear Ft. of Plate Edge: Cutting Time, Min.	Gas Consumption in Cu. Ft.: Oxygen	Gas Consumption in Cu. Ft.: Acetylene	Approximate Operating Time for Plates of Different Lengths, Min.*: 16	18	20	22	24	26	28	30	32
5/16	Square edge	6	7	1.0	9.5	11	12	13.5	14.5	16	17	18	19.5
	Single 30° bevel	6	9	1.4	9.5	11	12	13.5	14.5	16	17	18	19.5
	Single bevel and nose	7	12	2.2	11.5	13	14	15.5	17	18.5	20	21	22.5
	Double bevel and nose	..	..	...	..	..	..	..	..	..	..	..	..
1/2	Square edge	7	9	1.2	11.5	13	14	15.5	17	18.5	20	21	22.5
	Single 30° bevel	7	16	1.7	11.5	13	14	15.5	17	18.5	20	21	22.5
	Single bevel and nose	8	19	2.5	13	14.5	16	18	19.5	21	22.5	24	25.5
	Double bevel and nose	9	36	6.4	14.5	16.5	18	20	22	23.5	25.5	27	29
3/4	Square edge	8	16	1.5	13	14.5	16	18	19.5	21	22.5	24	25.5
	Single 30° bevel	8	21	2.1	13	14.5	16	18	19.5	21	22.5	24	25.5
	Single bevel and nose	9	44	4.3	14.5	16.5	18	20	22	23.5	25.5	27	29
	Double bevel and nose	9	48	6.4	14.5	16.5	18	20	22	23.5	25.5	27	29
1	Square edge	9	19	1.7	14.5	16.5	18	20	22	23.5	25.5	27	29
	Single 30° bevel	9	24	2.4	14.5	16.5	18	20	22	23.5	25.5	27	29
	Single bevel and nose	10	56	5.0	16	18	20	22	24	26	28	30	32
	Double bevel and nose	10	61	8.3	16	18	20	22	24	26	28	30	32

* Cutting of long edges governs overall cutting time. Since both of these are made simultaneously by movement of the same carriages, the time of travel of this carriage is equal to the overall production time of cutting all four edges of a plate.

are using oxyacetlyene welding equipment for the welding of brass, copper, aluminum and other special materials used in the equipment of ships. Much of the service piping is also oxyacetylene welded. Oxyacetylene heating is used for pipe bending and for straightening and correcting buckling which sometimes results from the welding of ship hulls, decks and superstructures. By far the greater number of all welding operators, however, are engaged in manual arc welding.

An estimated 800 men, however, are operating automatic electric welding equipment with which they can deposit metal at a much higher rate of speed than is possible with manual arc-welding equipment. These men, an operator and a helper to each special machine, are depositing metal by the Unionmelt welding process, welding with current densities in their welding rod of from 14,000 to 30,000 amperes per square in, and feeding steel welding rod through their equipment at rates of from about 1/3 pound per minute to about 1 pound per minute, depending upon the thickness of steel being welded.

Because of the high current density and the high rate of heat input into the weld, there are several things about the preparation for welding and the Unionmelt welding procedure which are unusual. In some yards, butt welds 3/8 inch deep are being made in one pass in plate that is square-butted tightly together without any beveled preparation. When beveling is used, the vees are smaller and the amount of metal required to complete the joint is much less than that required for the other welding methods commonly used by shipbuilders. Therefore, the 1/3 pound to 1 pound of rod melted per minute generally produces two to three times as much length of welded seam as would be produced with an equal weight of electrode used in other electric welding processes.

In spite of the high current densities used in Unionmelt welding, no excess heat is introduced into the joint because of the high speeds. Furthermore, the deep penetration of a single pass gives more uniform heating of the entire thickness of the joint and reduces the tendency to bowing of the welded pieces. Obviously, the fewer the number of passes, the less the cumulative shrinkage effect. Most types of joints are assembled for Unionmelt welding by simply butting them tightly together. All of these factors combine to eliminate the need for appreciable overall allowances for shrinkage of the automatic high-current, high-speed welds.

With this process there is no flashing arc to be seen. In fact, while the welding is going on, there is normally nothing to indicate even at close view that perhaps 30 to 90 Kw. of electrical energy are being transformed to heat, that welding rod is being melted at formerly unheard-of rates, and that almost twice as much base metal as added rod metal is being fused to form a homeogeneous, deeply penetrated weld.

The medium which makes this possible is a granulated material of special properties which is fed by gravity through the welding head and laid along the seam to sufficient depth to cover completely the welding zone and the end of the bare steel welding rod.

Except for the forward movement of the welding head, Figure 7 shows all there is to see of the welding action. The unfused granulated Unionmelt is shown covering the completed weld for about a foot to the right of the welding zone. Further to the right, the unfused material has been removed and the fused portion of the Unionmelt is shown slightly lifting away from the surface of the finished weld as both weld and solidified melt cool. The unfused material can be retrieved for re-use.

There is much variety in the equipment used in shipyards to take up the unfused granulated Unionmelt. The simple dust-brush and pan used in some yards is less common than some form of "vacuum-cleaner" type of

equipment. Such mechanical equipment must be specially designed to withstand the action of the highly abrasive material or vulnerable parts must be cheap enough to make frequent replacement economical.

The welding head shown in Figure 7 is a simplified, "stripped" unit suitable only for feeding straight lengths of welding rod for making welds requiring not over approximately 1000 amperes of welding current, which is about that required for making a fully penetrated weld ½ inch deep. This type of machine is simply constructed and easily portable. Figure 8 shows a complete unit of this type and of the latest design mounted especially to permit adjustment for making unpositioned fillet welds.

The welding units of the type shown in Figure 9 feed rod from coils of approximately 25 pounds weight and are used for making welds requiring up to about 2000 amperes. Welds of about 1¼-inch thickness can be made in one pass with this machine. The equipment can be readily moved about on flat surfaces but must usually be handled by crane for longer moves.

In Figure 10 the machine is shown welding a deck butt joint. The arrangement of this machine shown in Figure 11 was especially designed for fillet welding where guiding must be accurate with provision for following any waviness in the plate. The same type unit is shown in Figure 12 making the corner butt joint between the spar deck and shear strake of a Great Lakes ore freighter. At the left, in this picture, behind the arc-welding generator are shown the four 500-ampere welding transformers which are connected in parallel to supply the welding current to the automatic welding machine.

Most yards use 1000-ampere transformers either singly or connected in parallel; 440- or 220-v., 60-cycle, single-phase current is generally supplied to the welding transformers, although a few installations use 2300-v. supply sources.

A few welding heads are supplied with direct current from standard welding generators. Regardless of the source of current, provision is made to make and break the supply current instantaneously at full load for starting and stopping a weld. A contactor operated from a small switch on the welding head is standard equipment. The contactor to control the welding current may be in the primary supply lines to the welding transformers, in the output circuit of DC generators, or, if the generator field circuits can be isolated, a small contactor in the field circuit will suffice.

A large, heavy type of welding head which is in no sense portable was the first one used with Unionmelt welding. This head, illustrated in Figure 13, must be mounted on a substantial supporting structure. It is capable of feeding as much as 4000 amperes of welding current to welding rod as large as ½ inch in diameter.

Two of these large heads were installed in 1936 in the shipyard in which Unionmelt welding units were first used in shipbuilding. Since that time, many of the smaller units and additional large heads have been put in service in that yard. The highly developed methods of construction at that yard, and the use of large auxiliary mechanical equipment especially designed for mass production of tankers, have led to a greater use of automatic welding than is found in any other shipyard. Figures 14 and 15 show a part of the installation of the large automatic welding equipment, and Figures 16 and 17 show closer views of welding with the large heads.

In all other yards, only the smaller, portable units have been used and good results are being obtained. At the present rate of expansion of use, there will probably be 1500 men using these automatic welding machines in another year.

The use of this process in shipbuilding has been, and will be even more in the immediate future, an important factor in speeding welded construction.

One operator and a helper can produce from 200 to 400 feet per 8-hour day of finished seam in steel of average ship-plate thickness. Hence the use of this process releases many an arc-welding operator for the greater amount of welding which on any ship is not adaptable to automatic machine methods.

Prefabrication is the principal field of application of the Unionmelt welding process, although in many yards the machines are taken onto the ways for the welding of shell bottom plating, tank tops and decks. The prefabrication includes the welding of sections of tank tops, shell plating, bulkheads, shaft alleys and decks, as well as sections of superstructure, and king posts and booms of cargo-handling equipment.

Butt welds and fillet welds are the types principally made. Smaller fillets of less than about ⅜-inch leg dimension are frequently made without positioning the pieces, but the large fillets tend to sag, and the pieces must usually be tilted so that the diagonal surface of the weld will be approximately horizontal.

In the making of butt welds, full advantage of the deep penetration of Unionmelt welding and its consequent capacity to weld considerable thicknesses in one pass cannot be taken unless some means are provided for supporting the molten metal from the under side. Several methods of backing welds and of combining manual arc welding and automatic Unionmelt welding are indicated in the tables of data for various types of joints used in shipbuilding.

Both types of Joint 1, illustrated, require tightly fitted edges to prevent the weld metal from flowing through, but for plate thicknesses less than ½ inch, contact with a platen or structural members on which the subassembly is laid is usually needed for additional chill to control the fluid metal.

The edges must be straight and fitted tightly enough to exclude a shipfitter's feeler. If mill-sheared edges are used, it may be necessary to grind or otherwise condition the edges to obtain this result.

The weight of the plates assembled on a platen is usually sufficient to maintain satisfactory contact, but it may be necessary to hold them down by weights, roller or structural means.

Joint 3 requires uniformly close and tight contact between the underside of the seam and the copper-backing to prevent the weld from running out.

Uniformly sound welds require removal of all surface scale, rust and other material so that clean metal is exposed on the surfaces in contact with the copper-backing-up means.

In Joint 4 the manual welds replace the initial Unionmelt weld of Joint 1. The manual weld must be sound, uniformly reinforced and of a depth (measured by penetration plus reinforcement) at least one-half the plate thickness for plates up to ½ inch thick in order adequately to back the finishing Unionmelt weld and assure complete overlapping.

The top manual pass in Joint 4-C should be thoroughly cleaned of slag before Unionmelt welding.

With Joint 5 the steel backing bar should bear uniformly on the underside of the seam in order to prevent fluid metal from running out.

If considerable variation in edge-bevel and edge-distance is encountered, it should be compensated for by variation in welding speed to maintain desired reinforcing. The distances between the edges and the bevels tabulated are the minimum allowable.

If Joints 6 and 7 are not fitted tight, some method of damming the molten metal must be employed so as to prevent a runout.

Cleaning by grinding or wire-brushing of the surfaces to be welded will permit the use of highest welding speeds and help to produce uniformly sound welds.

Joint No. 1—Two-Pass Unionmelt Butt Welds*

*Joint Backed with Platen or Heavy Structural Shape

	Backing Pass					Finishing Pass					
Thickness, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Lb./Ft.	Amp.	Volts	Speed, In./Min.	Welding Rod Diam., In.	Lb./Ft.	Total Vee Angle θ, °
1/4	400	32	28	5/32	0.10	500	30	27	5/32	0.12	
5/16	420	32	28	5/32	0.11	550	30	26	5/32	0.15	
3/8	500	32	28	3/16	0.14	600	32	24	3/16	0.18	
7/16	600	33	24	3/16	0.20	700	35	22	3/16	0.25	
1/2	700	33	22	3/16	0.23	750	35	20	3/16	0.27	

9/16	650	33	22	1/4	0.21	900	31	20	1/4	0.38	90
5/8	650	33	22	1/4	0.21	950	31	18	1/4	0.44	90
3/4	700	33	22	1/4	0.23	1000	33	16	1/4	0.50	75
7/8	700	33	22	1/4	0.23	1100	35	14	1/4	0.60	60
1	700	33	22	1/4	0.23	1200	35	12	1/4	0.75	45

* Used for keel plating seams, tank tops, tweendecks, bulkheads, etc.

Joint No. 2—Melt-Backed Unionmelt Butt Welds

Joint No. 2—Melt-Backed Unionmelt Butt Welds

Table I

Thickness, In.	Edge Preparation	Ampere	Volts	Speed, In./Min.	Welding Rod Diam. In.	Welding Rod Lb./Ft.	Air Pressure Lb./Sq. In.
1/4	Square	960	42	38	1/4	0.15	70
5/16	Square	960	42	36	1/4	0.17	70
3/8	30° vee, no nose	900	40	32	1/4	0.20	65
7/16	30° vee, no nose	920	37	26	1/4	0.26	65
1/2	30° vee, no nose	960	37	22	1/4	0.33	60
9/16	30° vee, no nose	960	35	20	1/4	0.36	55
5/8	30° vee, no nose	1020	35	18	1/4	0.44	50
3/4	30° vee, no nose	1080	35	15	5/16	0.53	45
7/8	30° vee, no nose	1160	35	10	5/16	0.91	45
1	30° vee, no nose	1250	35	8–9	5/16	1.15	45

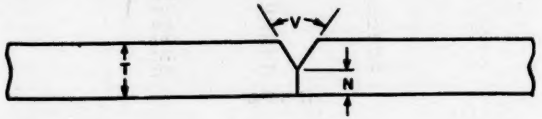
Above tabulated conditions provide reinforcement or flat bead on backs of welds.

Table II

1/4	Square	700	32	21	1/4	0.22	35
5/16	Square	720	32	21	1/4	0.25	35
3/8	Square	760	32	18	1/4	0.33	35
7/16	30° vee, no nose	800	32	17	1/4	0.37	35
1/2	30° vee, no nose	860	32	17	1/4	0.40	35
9/16	30° vee, no nose	900	31	17	1/4	0.45	35
5/8	30° vee, no nose	960	31	14	1/4	0.55	35
3/4	30° vee, no nose	1020	33	10–12	5/16	0.69–0.83	35
7/8	30° vee, no nose	1150	34	9–10	5/16	0.91–1.01	35
1	30° vee, no nose	1200	34	8	5/16	1.17	35

Above tabulated conditions provide flat to grooved backs on welds.
In both of the above cases backing melt is 3 1/2 in. deep above a 3 1/2-in. diameter fire hose.

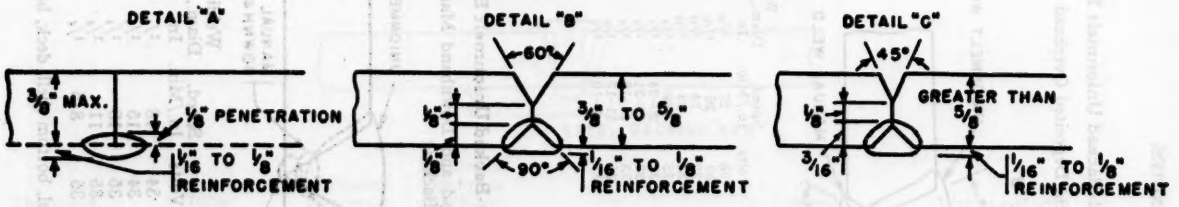
Joint No. 3—Copper-Backed Unionmelt Butt Welds



Thickness, In.	Vee, °	Nose, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam. In.	Welding Rod Lb./Ft.
3/16	60	1/8	500- 575	28-31	29-35	3/16	0.11-0.13
1/4	60	1/8	725- 825	29-32	28-31	3/16	0.14-0.23
5/16	60	1/8	775- 900	30-33	26-29	1/4	0.25-0.30
3/8	60	1/8	900-1000	32-36	24-27	1/4	0.28-0.35
7/16	60	1/4	1000-1100	32-36	22-25	1/4	0.33-0.40
1/2	60	5/16	1075-1175	34-37	20-23	1/4	0.38-0.45
5/8	45	3/16	1150-1250	35-38	16-19	1/4	0.50-0.58
3/4	45	3/16	1200-1300	36-39	13-14	1/4	0.60-0.75
7/8	40	1/8	1375-1500	38-40	11-13	5/16	0.80-0.95
1	35	1/8	1500-1600	39-41	10-12	5/16	0.90-1.10
1 1/8	30	1/8	1575-1650	39-41	9-10	5/16	1.00-1.25
1 1/4	30	1/8	1600-1700	39-41	8- 9	5/16	1.25-1.60
1 1/2	30	1/8	1900-2000	40-43	7- 8	3/8	1.85-2.00

Joint No. 4—Manual Weld-Backed Unionmelt Butt Welds

(*A*) Manual Weld Deposited in Downhand Position
(Plate Turned Over for Unionmelt Welding)

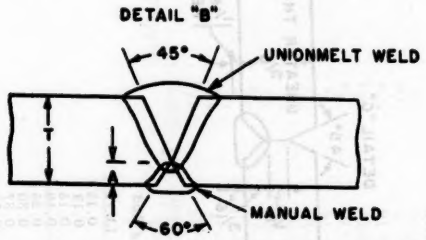


CONDITIONS FOR UNIONMELT WELDING

Thickness, In.	Detail	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Welding Rod Lb./Ft.
5/16	*a*	500	28	27	5/32	0.12
1/4	*a*	550	28	27	5/32	0.13
5/16	*a*	600	30	26	5/16	0.15
3/8	*a*	650	32	24	5/16	0.18
7/16	*b*	750	33	22	5/16	0.25
1/2	*b*	850	33	22	1/4	0.30
5/8	*b*	950	33	20	1/4	0.37
3/4	*c*	1050	35	16	1/4	0.50
7/8	*c*	1150	35	13	1/4	0.60
1	*c*	1200	35	11–12	1/4	0.80

Joint No. 4—Manual Weld-Backed Unionmelt Butt Welds

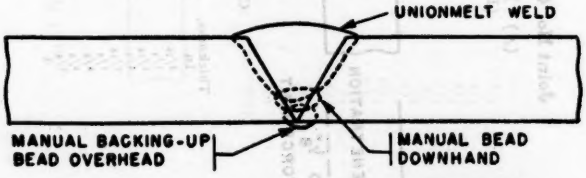
(*B*) Manual Weld Deposited Overhead



Thickness, In.	Detail	*A*, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Welding Rod Lb./Ft.
1/4	a	1/8	550	28	27	3/16	0.13
5/16	a	1/8	600	30	26	3/16	0.15
3/8	a	3/16	650	32	24	3/16	0.18
7/16	a	3/16	750	33	22	3/16	0.25
1/2	b	1/4	850	33	22	1/4	0.30
9/16	b	1/4	900	33	20–24	1/4	0.30–0.37
5/8	b	1/4	950	33	18–21	1/4	0.33–0.38
3/4	b	1/4	1050	33	14–16	1/4	0.50–0.57
7/8	b	1/4	1125	35	11–12	1/4	0.65–0.71
1	b	1/4	1200	37	9–10	1/4	0.85–0.95

Joint No. 4—Manual Weld-Backed Unionmelt Butt Welds*

(*C*) Combination Overhead and Downhand Manual Weld Backing



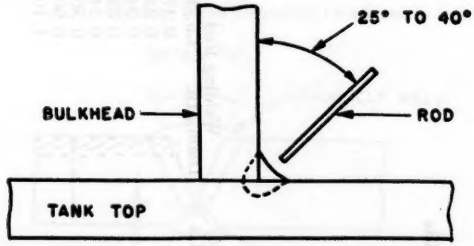
Thickness, In.	Vee, *	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Welding Rod Lb./Ft.
3/8	30	650	34	18	1/4	0.30
7/16	30	700	34	15	1/4	0.35
1/2	30	700	35	13	1/4	0.40
5/8	30	750	35	11	1/4	0.50
3/4	30	750	35	8.5	1/4	0.60

* Used as shown for flat keel, bottom shell, deck, bulkhead and tank top joints.

Joint No. 5—Integral Steel-Backed Unionmelt Butt Welds

Thickness, In.	Edge Preparation	Minimum Spacing, In.	Minimum Thickness Backing Bar, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Welding Rod Lb./Ft.
1/4	Square	3/16	1/4	950	27	34	1/4	0.17
5/16	Square	3/16	5/16	1000	27	27	1/4	0.23
3/8	Square	3/16	3/8	1000	27	26	1/4	0.24
7/16	30° Vee	1/4	3/8	1100	27	22	1/4	0.32
1/2	30° Vee	5/16	3/8	1200	27	16	1/4	0.54
9/16	30° Vee	5/16	1/2	1200	27	12	1/4	0.80
5/8	30° Vee	3/16	1/2	1200	28	11	1/4	0.90
3/4	30° Vee	5/16	1/2	1200	28	9	1/4	1.10

Joint No. 6—Non-Positioned Unionmelt Fillet Welds*



Normal Fillet Size, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Lb./Ft.
1/8	350	27	34	1/8	0.06
5/16	350	28	30	1/8	0.09
1/4	450	28	25	1/8–5/32	0.14
5/16	500	28–30	22	5/32	0.20
3/8	550	30	18	5/32	0.31
1/2	750	33	12	3/16	0.53

* Used for joining bulkheads to tank tops, etc.

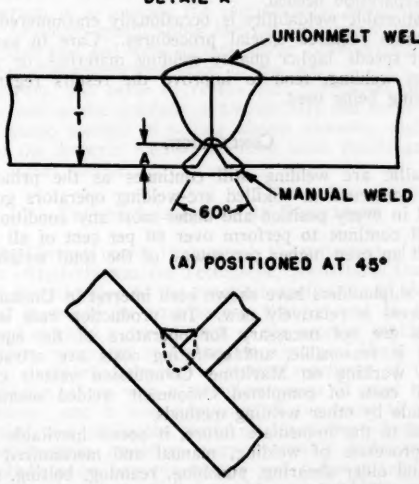
Procedures differ in detail in various shipyards, but generally the assembly of sections of hull, inner bottoms, bulkheads and deck starts with the laying of the prepared plates on a large platen or on a skeleton table made of T-bars, I-beams or other structural steel shapes. Partly penetrated automatic welds are then made and the stiffeners are fillet welded to the plate which is then turned over and automatically welded from the other side, with ample penetration into the weld previously made from the first side.

Frequently, the hull bottom plates are laid individually on the ways, an overhead weld is made on the underside of the plate by manual arc welding and, with this as backing, a Unionmelt automatic weld is made from above. Similar procedure is often used in applying deck or tank top plating, although sometimes the plate joints land on a flanged structural member or are fitted with a steel backing strip, and a weld with cross sections like that shown in Figure 18 is made. The scene in Figure 19 shows typical operation on bottom and deck weldings.

Plug welding is an operation of ship construction for which the Unionmelt process is well suited. Recently one shipbuilder found it was possible to produce as many as 76 plug welds per hour with one portable Unionmelt welding machine, fastening ½-inch tank top plating to the flanges of angle-iron supporting structures. Figure 20 shows a typical section of a plug weld and Figure 21 illustrates the making of plug welds with standard equipment. Simple, light-weight, hand-operated equipment has recently been introduced to facilitate plug welding.

With all methods of welding, cleanliness of plate edges and weldability of material are vital to success. Manual metallic arc welds are often made with fair success but with questionable economy on plate which is wet, oily or dirty. Such conditions, however, are usually not tolerated.

Joint No. 7—Positioned Unionmelt Fillet Welds



Normal Fillet Size, In.	Amperes	Volts	Speed, In./Min.	Welding Rod Diam., In.	Lb./Ft.
1/8	400	27	36	1/8	0.04
3/16	500	27	32	1/8	0.07
1/4	650	27	28	3/16	0.11
5/16	650	28	22	3/16	0.17
3/8	750	29	18	3/16	0.25
1/2	850	31	16	1/4	0.43
5/8	950	31	13	1/4	0.66
3/4	1080	31	11	1/4	0.95

NOTE: These conditions if used in applying a fillet to each side of the web plate will yield 100% penetrated tee joints with the work positioned at 45° where the thickness of the web plate is equal to or less than the size of the fillet leg.

In Unionmelt welding, freedom from gas-forming contaminants in the fusion zone is particularly important because of the unusually high welding speeds and the resulting rapid rates of initial cooling of relatively large volumes of molten metal in the weld. Contaminating materials such as water, oil, paint, heavy scale and rust are usually removed by wire brushing or rapid surface heating with a concentrated oxyacetylene flame. If the plates are carefully protected and the work of assembly and welding is properly organized, a light wire-brushing just before welding will be the only surface preparation needed.

Steel of questionable weldability is occasionally encountered in shipyards and has sometimes required special procedures. Care in assembling and cleaning, slower speeds, higher quality welding materials, or perhaps additional passes of welding, tend to improve the results regardless of the method of welding being used.

Conclusion.

Manual metallic arc welding still continues as the principal welding method in ship construction. Skilled arc-welding operators go everywhere on a ship, weld in every position and under most any conditions. Without doubt, they will continue to perform over 60 per cent of all ship welding and will deposit an even higher percentage of the total weight of welding rod used.

Nevertheless, shipbuilders have shown keen interest in Unionmelt welding, though the process is relatively new. Its production rate is high; long training periods are not necessary for operators of the equipment; the investment cost is reasonable, and operating costs are attractive. From some shipyards working on Maritime Commission vessels come reports that the overall costs of completed Unionmelt welded seams are about half of those made by other welding methods.

Looking ahead to the immediate future, it seems inevitable that manual and automatic processes of welding, manual and mechanized methods of flame cutting, and older shearing, punching, reaming, bolting, riveting and calking processes will all be used to the limit during the coming months, for the nation's shipyards are being called upon to produce four million tons of cargo shipping per year by 1943, and a two-ocean Navy by 1947. No method of construction will be overlooked in this emergency effort, providing it produces the maximum results with the equipment and man power which are available. But, undoubtedly, out of this situation calling for the utilization of all processes, will come valuable comparisons and technical production data which will guide us in choosing the most economical and efficient methods of building ships in years to come when world conditions again return to normal.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

DYNAMIC TESTING IN GERMANY.—This brief survey of modern German dynamic testing technique was prepared by Herbert Nelson Cox, of the firm of W. and T. Avery, Ltd., Birmingham. It is reprinted from the Journal and Proceedings, Institution of Mechanical Engineers, November, 1941.

Introduction.

The examination of the fatigue properties of materials is now well established throughout the world; and with the development of high-speed machinery has come the realization that it was necessary to develop the study of the dynamic properties of constituent members of complete machines.

The application of this method of testing rendered particular service to industrial production in Germany before the present war, and the purpose of this monograph is to indicate the specialization which had taken place in this field. Although specifications had not been issued for dynamic tests, proposals towards that end were already under consideration by the leading German industrial organizations prior to the war.

German industry was early to realize that the advent of quick-running machinery, as well as the products of the aircraft and motor car industries, rendered the static method of testing almost obsolete, and increased the importance of the dynamic method as being more nearly analogous to the conditions of actual service.

Testing Laboratory at Darmstadt.

Probably the German center from which the principles of dynamic testing radiated most effectively was the Technische Hochschule, Darmstadt. Great attention had been devoted to the practical application of the test to actual products, and it would be true to say that it was to this center that Germany owed so rapid a development of the practice within her industries.

The laboratory equipment at Darmstadt Technical High School was very complete, and included some thirty testing machines of the usual static type. In addition, there was a complete series of over seventy dynamic testing machines; and it was significant of the trend in modern German testing practice that while the static machines were becoming somewhat dormant, the dynamic machines were invariably fully employed. There was close collaboration between science and industry, and it was to this school that German industrialists brought their problems of design.

100-ton Dynamic Testing Machine.

The largest type of dynamic testing machine in use in the laboratory at Darmstadt had a maximum capacity of 100 tons. It was of the vertical "pulsator" type, and a number of machines of this class had been employed in the industrial areas in Germany for some years.

Figure 1 shows diagrammatically the general scheme of the machine. It will be noted that a pressure pump supplies oil to one of two cylinders, thus providing the means for applying static loads to the specimen, up to a maximum of 50 tons.

The second hydraulic cylinder is subject to a pulsating pressure set up by a pulsator operated by a rocking lever. This device enables vibratory loads to be applied, up to a maximum of 50 tons, and these loads may be superimposed upon the initial static load.

The compression pulsating loads are produced by an air vessel which serves the purpose of a spring. The machine thus provides means for applying pulsating loads in tension and compression over and above the initial static load, and is capable of carrying out flexure tests upon beams, or pulsating tension or compression tests upon various large machine components.

As the maximum speed of the machine setting up the number pulsations is only in the neighborhood of 500 RPM, the rate at which the pulsations are produced is low, and the testing operation tends to be somewhat prolonged.

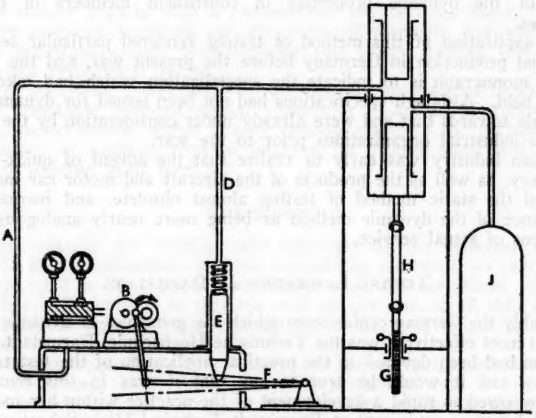


Fig. 1. General Arrangement of 100-ton Dynamic Testing Machine

A Pump supply.
B Motor.
C Eccentric.
D Pulsator supply.
E Pulsator.
F Rocking lever.
G Screw adjustment.
H Specimen.
J Oil vessel.

20-ton Pulsator Testing Machine.

A smaller pulsator type of testing machine, produced locally at the works of Messrs. Schenck, was also installed in the laboratory, and there were a number of examples in use. This machine is shown complete in Figure 2, and its method of operation will be understood from the diagram, Figure 3.

In this machine, which has been installed in a number of works laboratories in various parts of Germany, the repetitions are applied at about the rate of 3000 per minute. The machine was of the type known as "push-pull," and permitted specimens to be tested under reversed axial stresses, either alone, or in conjunction with an additionally applied static load. It thus produced all the stressing operations of the stress range diagram.

The machine was specially adapted for the purpose of testing dynamically larger parts of machinery, and in Figure 4 a motor car crankshaft is shown in position for test.

Details of 20-ton Machine.

In construction, the machine comprises a heavy base-box upon which is supported transversely a flat steel spring beam. The specimen to be tested is secured at one end in a holder attached to the center of the beam;

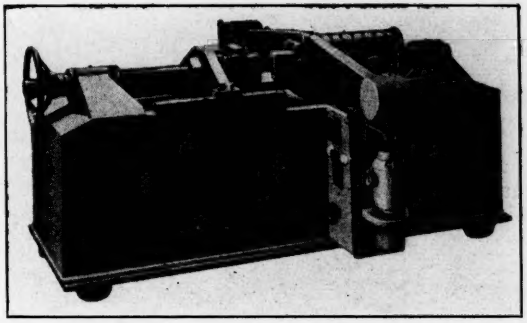


FIGURE 2.—EXTERNAL VIEW OF 20-TON PULSATOR TESTING MACHINE.

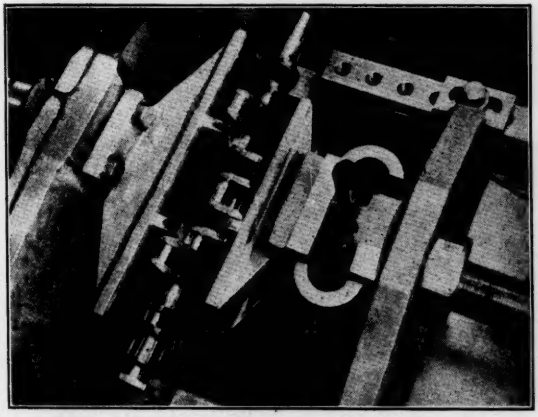


FIGURE 4.—MOTOR CAR CRANKSHAFT IN POSITION FOR TEST.

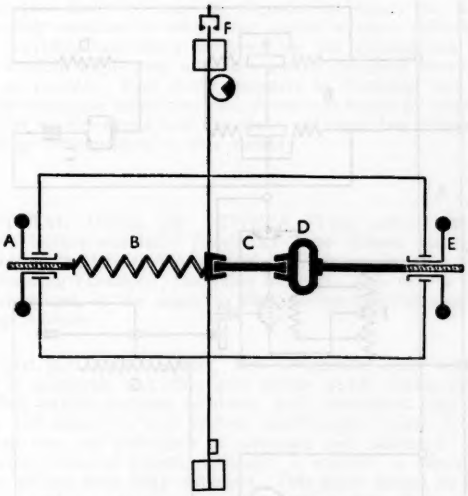


Fig. 3. Action of Pulsator Testing Machine

A Adjustment of static initial load.
B Spring for applying static stresses.
C Specimen.
D Measuring equipment.
E Adjustment of size of specimen.
F Regulation of amplitude.

at the other end it is connected by a second holder to a "loop" type of measuring dynamometer. Behind the spring beam are attached two heavy coil springs, the purpose of which is to apply an initial static load, the magnitude of which is determined by the loop dynamometer and measured by a microscope having a graduated eyepiece.

The purpose of the spring beam is to apply pulsating stresses to the specimen. When in use, the beam is caused to vibrate by the action of an exciter attached to one of its ends. The exciter, which is driven by an electric motor through a flexible shaft, consists of a shaft provided with unbalanced disks which, on rotation, cause vibrations to be set up in the spring beam. These vibrations are transmitted to the specimen secured at its center. The number of stress cycles applied to the specimen by the vibrating spring beam can be varied between 2600 and 3000 per minute.

The initial static load produced by the two coil springs may be varied between zero and a maximum of ± 10 tons, while the pulsating load may be adjusted—while the machine is in operation—up to a further load of 10 tons in either direction. These two loading capacities thus make up a maximum total of 20 tons. A special provision with this machine is an electric device for maintaining a constant amplitude for the spring beam, notwithstanding any possible fluctuation in the voltage of the supply to the electric motor. This device is shown diagrammatically in Figure 5.

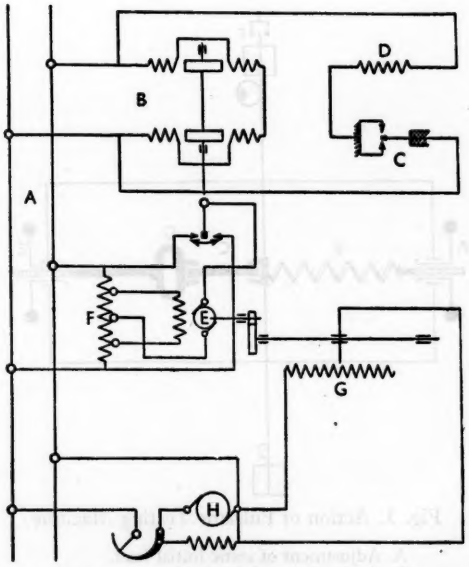


Fig. 5. Method of Maintaining Constant Amplitude for Spring Beam

A Mains supply.	E Regulating motor.
B Differential relay.	F Voltage divider.
C Regulating contacts.	G Regulating resistance.
D Balancing resistance.	H Driving motor.

In dynamic testing, it is essential that the prescribed load be applied with all due regard to accuracy, and as the machine in question is free from heavy moving parts, undetermined stresses due to inertia are practically eliminated.

Conclusion.

The two machines described are mainly designed for testing complete details of machinery, although the advantage of being able to test large specimens of material in the same machine is retained. For the general testing of material as an aid to a proper selection to meet conditions of repetitions of stress, small machines of a different type were employed at Darmstadt.

The brief survey of this section of modern German testing technique indicates that their engineers were directing great attention to the comparatively recent innovation of dynamic testing of full-size details of machinery. In this country, too, the author's firm have been experimenting for some time with such machines, and have developed certain types for industrial purposes.

The examples described may be regarded as types, but the principles underlying their construction were being applied in many variations with the object of providing laboratory facilities for the examination of problems arising in modern high-speed machines and of imitating service conditions as nearly as possible. Part of the incentive in Germany was provided by the need for substitute materials; and at the conclusion of hostilities it will be interesting to determine how far their technique has differed from the corresponding developments in this country.

INDUSTRIAL USES OF JEWELS.—This account of Mr. Paul Grodzinski's lecture entitled "Jewels in Time Pieces and Instruments," delivered before the British Horological Institute on June 11, 1941, is taken from Engineering (London), December 26, 1941. This review of his lecture has been restricted, in the main, to the sections bearing more directly on engineering practice.

In the first part of his lecture, Mr. Grodzinski dealt with the special properties of diamonds and other gem stones which distinguish them from metals. They exhibit extreme hardness, with consequent high resistance to scratching and abrasion; low friction co-efficients, owing to their single-crystal structure; and resistance to corrosion and oxidation. The diamond is the hardest mineral known, although it exhibits a range of hardness which has not yet been fully explored. This point should be kept in mind

TABLE I.—INDUSTRIAL APPLICATIONS OF DIAMONDS AND OTHER MINERALS.

Application.	Diamond	Corundum.		Quartz.	Garnet.
		Natural.	Synthetic.		
As bearings—					
Knife edge ..		+	+	+	
Cylindrical ..		+	+	+	+
End stones ..	+	+	+		+
Cup (pivot)	+	+	+		
As wear resisting materials					
Plates ..	+				
Hemispheres	+				
Nozzles for oil burners ..	+				
Mortars and pestles ..				+	+
Gramophone records					
Cutting points	+	+	+		
Reproducing points ..	+	+	+		
In scientific instruments—					
Hardness testers ..	+				
Scratching records	+	+			
Optical lenses	+			+	

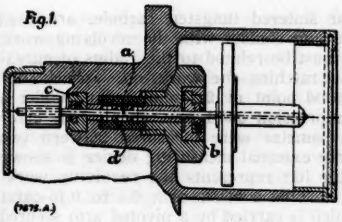
when selecting stones. Owing to difficulty in machining, diamonds are in general, used only as wearing-plate end stones in highly accurate chronometers and as bearing or scratching points in hardness-measuring appliances. For other industrial applications, minerals of lower hardness are used, as indicated by the crosses in Table I.

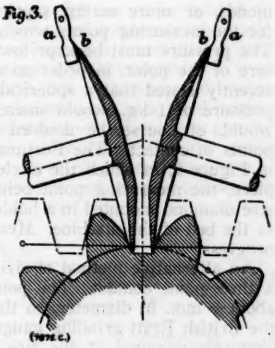
Precious stones other than diamonds vary considerably in their degree of hardness. Australian sapphires are the most resilient and yellow sapphires the hardest. Sapphires are harder than rubies and Ceylon sapphires harder than Kashmir sapphires. Synthetic rubies were first produced about 30 years ago, and about 90 per cent of jewel bearings in watches are now synthetic. For knife-edge bearings, chemical mortars and pestles, and similar applications, such materials as agate, especially chalcedony and carnelian, have hitherto been used. They are found in larger pieces than other suitable natural stones. Synthetic sapphires may perhaps be used in the future. The diamond has seldom been used for bearings, on account of its high cost and the difficulties involved in cutting and polishing. The manufacture of precise forms and sizes for interchangeable production is very difficult. Sintered materials of great hardness have recently been produced which, for some purposes, may take the place of natural and synthetic gem stones. They include sintered tungsten, titanium, or tantalum carbide and boron carbide. In spite, however, of attempts to improve the microstructure of these materials, they still consist of multiple crystals in a softer matrix, whereas gem stones have a more or less single-crystal structure.

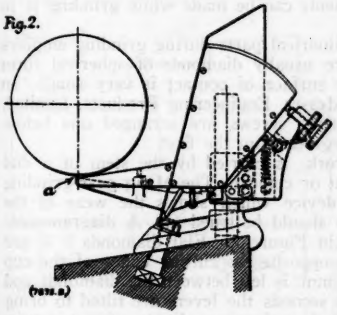
Bearings and Pivots.

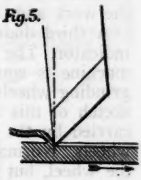
When jewels are used for bearings, the spindle diameter and hole are kept to a minimum, in order to reduce friction. Cylindrical bearings of sapphire or ruby are now produced in quantity by special machinery and are available for general application. Two such bearings are utilized in the Warren synchronous clock motor which is illustrated in Figure 1, on this page. The rotor spindle *a*, which revolves at 3000 RPM., is carried by two cylindrical jewel bearings, one *b* at the rotor end, and the other *c* at the gear end. Between them is an oil-impregnated cotton-wool pad *d*, separated from the spindle by a perforated sleeve. In a wrist-watch, out of 26 different bearings, 11 are usually of the jewel type and comprise 13 single stones. Some watches have as many as 21 rubies. Pivot bearings consist of a plain drilled jewel against which runs a shoulder on the spindle, or, alternatively, an end bearing jewel is provided in addition. This is a better arrangement, the radial and axial thrusts being taken by separate jewels. The jewels have cavities for lubricating oil.

Conical pivot bearings are preferable in wattmeters, compasses and other instruments, as they give the minimum friction. The position-control of the spindle, however, is not very accurate. When used in a horizontal position, the axial backlash results in a small downward displacement of the spindle and an increased friction torque. With a vertical arrangement, the bearing and spindle are coaxial and the friction drag is very slight. Steel pivots are common, but as early as 1840 experiments were made in the use of other alloys. Kinnard and Goss found that steel points of 0.0185 inch radius broke easily, but cobalt-tungsten alloy pivots of the same size were satisfactory. Cobalt-tungsten pivots are softer than steel pivots and tend to flatten slightly, reducing the unit pressure on the jewel without measurably increasing the friction. The ratio of the radius of the pivot to the radius of the cup should be approximately 7 to 10. Corrosion is avoided if the point and cup are made of different minerals; jewel pivots in jewel cups have been used for some years. The cup may be of sapphire and the point of agate;









or the cup of diamond and the point of sapphire. An application of this kind is found in the 1917 Admiralty standard compass, which has a sapphire cup and an agate pivot point. Compass jewels are highly stressed owing to the small movement of the needle and the shock loads, particularly in the case of aircraft instruments. A recent British Standard Specification, No. 904-1940, covers cylindrical pivot bearings, conical pivot bearings, end stones and three designs for compass stones. It is not intended for application to watches or integrating meters.

In contradistinction to circular bearings, knife-edge bearings are subjected only to a limited swinging motion, with little friction. The knife-edge and seat, however, may be subjected to considerable shock. Such bearings, in general, are used only in scales and fine measuring instruments. For scales, agate is frequently used, although it has only a hardness of 6 on Mohs' scale. It can easily be obtained in the requisite sizes, and, if necessary, ground and polished in position.

Wear-Resisting Plates.

The first use of jewels as wear-resisting plates seems to have been for pallets in watch and clock escapements. The earliest application was probably by the famous British clockmaker, Mudge, in about 1754. The use of jewel bearings in watches is older, the first record being found in the British patent of Facio and Debaufré, of 1704. Compass jewels seem to have been first used by Servington Savery, of Chilston, in 1705, but did not come into common use until the second half of the Eighteenth Century; even then glass plates were frequently used.

Jewels are used for wear-resisting surfaces in various measuring appliances, employed, for example, in connection with grinding operations. Dia-

monds, or more rarely, sapphires or sintered tungsten carbide, are used for the measuring points which come into contact with the revolving work. The pressure must be kept low and must be related to the radius of curvature of the point, in order to avoid scratching the work. H. Törnehohm* recently stated that a spherical diamond point of 2.5 mm. radius, under a pressure of 1 kg., would make an impression 0.001 mm. deep. This error would, of course, be doubled if a diameter were measured between two points of contact. The Fortuna-Werke external measuring device is shown in Figure 2, in which the circle on the left represents the revolving workpiece, the measuring point being at *a*. This consists of a 0.1 to 0.15-carat size diamond mounted in a holder, which is carried by a pivoted arm secured to the bed of the machine. Measurements can be made while grinding is in progress.

An alternative method of sizing cylindrical parts during grinding employs a three-point contact. The points are usually diamonds of spherical form about 2 mm. in diameter, so that the surface of contact is very small. In the British Pratt grinding gauge of Messrs. Engineering Products, Limited, diamonds mounted at the tips of setting screws are arranged one below the work and the other in front, 90 degrees from the first.

A third diamond, on top of the work, is carried by the stem of a dial indicator. The diamond points are flat or conical. The Maag gear-grinding machine is equipped with a contact device which shows the wear of the grinding wheels, indicating when they should be trued up. A diagrammatic sketch of this arrangement is given in Figure 3. Flat diamonds *b b* are carried by the levers *a a* in positions opposite the cutting edges of the cup wheels. Normally a space of about 1 mm. is left between the diamonds and the wheel, but at intervals of about 5 seconds the levers are tilted to bring the diamonds into contact with the wheels under very slight spring pressure. The wear of the wheels measured in this way is indicated on a gauge.

Contact diamonds are applied, not only for automatic sizing arrangements of this type, but also for precision gauges in which frequent measurements are made on the same point. An example is furnished by pitch-diameter gauges for threads. In such cases the diamonds are formed with a point having an included angle of 55 degrees to 60 degrees, corresponding to the thread. Where the precision demanded is not so high, such materials as sintered carbide may be used instead of diamonds; their wear-resisting properties are higher than that of hardened steel.

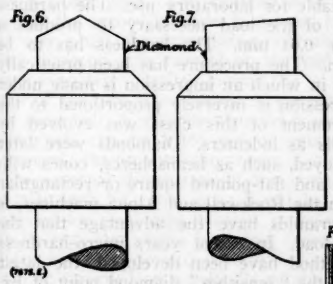
Owing to the low price of crude oil in the United States, domestic central-heating plants fitted with automatic oil burners have come into extensive use. The abrasive action of the oil spray is found to enlarge the fine holes in the nozzles in a relatively short time and diamond nozzles, on the lines of the diamond dies used for wiredrawing, have been recently introduced. The results have been very satisfactory and show considerable saving. Although the initial cost of the nozzles is high, they have a long life and give a uniform rate of oil consumption. With metal nozzles, owing to wear, the oil consumption has a tendency to increase. It is worth considering whether diamond nozzles might usefully be employed for Diesel-engine fuel injection, water sprays and sand blasting.

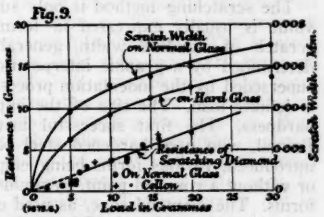
Gramophone Cutting and Playing Needles.

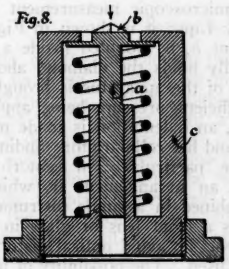
As is well known, ordinary steel needles used with gramophone records wear so quickly that they can only be used once. Various alternatives are in use, but for cutting, when manufacturing records, sapphire or diamond

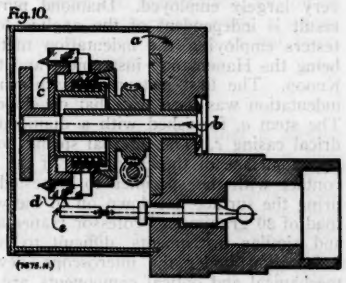
* Schweizer Archiv. f. angew, Wissenshaft und Technik, Nov., 1939.

needles are employed. The shape of the cutting point has to be related to the material being cut. A tool with a negative rake angle, as shown in Figures 4 and 5, opposite, is often used but it has been found that a tool without any rake gives the most satisfactory results. When sapphire is used it is possible to make needles accurately to form, but with diamonds, owing to the difficulties of cutting and polishing, the maintenance of a fixed cutting angle is not easy. This disadvantage of diamond needles has been met by means of gauges supplied by the manufacturers, which ensure that the needle is set so as to present the correct cutting angle to the work. Such appliances as dictating machines are furnished with diamond needles polished to









definite angles. Figures 6 and 7 show the type of diamond point which has been used successfully on a Continental dictating machine, using gelatine discs. A new process for the production of gramophone records has recently been introduced in America. It avoids the use of wax-plates from which shellac masters are made. A thin aluminum disc is cut with a diamond point and, from this, a negative is made from a thermo-setting resin. This negative is then used as a master for the production of discs for general use.

Hardness Testing.

The testing of hardness by means of a sharp crystal point was one of the earliest scientific applications of minerals. The ancient Indians and Greeks rubbed two stones together to ascertain, by scratch or sound, which was the

harder, the method later being extended to the use of testing points and needles for the identification of minerals. A further step was the evolution of the scratch hardness tester. This type of instrument, which was invented by Seeberg in 1830, and later improved by Martens, invariably employed diamond points. It ultimately developed into modern hardness testers which employed microscopic examination to observe the finest scratches and indentations. The first micro-hardness tester was introduced by V. Poeschl, in 1909, and was followed by the instruments of Bierbaum and Zeiss. The scratch, in the case of the Bierbaum instrument, was made by the corner of a diamond cube; Zeiss employed a chisel point or cone with an included angle of 120 degrees. In the earlier work of Martens the angle was 90 degrees.

The scratching method is only suitable for laboratory use. The hardness value is usually expressed in terms of the load necessary to produce a scratch of standard width, generally 0.01 mm. The hardness has to be determined by a graphic interpolation. The procedure has been practically superseded by the indentation process in which an impression is made under a definite load. The size of the impression is inversely proportional to the hardness. The first successful instrument of this class was evolved by Brinell, who used hardened steel balls as indenters. Diamonds were later introduced, various forms being employed, such as hemispheres, cones with or without a rounded point, pyramids, and flat-pointed square or rectangular forms. The diamond cone, as used on the Rockwell and Alpha machines, is very largely employed. Diamond pyramids have the advantage that the result is independent of the applied load. In recent years micro-hardness testers employing the indentation method have been developed, the latest being the Hanemann* instrument and the "sensitive" diamond point of Fr. Knoop. The first instrument with which microscopic measurement of the indentation was used was that developed by Lips; it is shown in Figure 8. The stem *a*, furnished with a diamond point *b*, is mounted inside a cylindrical casing *c*. The internal spring normally holds the diamond above the upper surface of the casing, but if the end of the apparatus is brought into contact with the specimen to be tested, sufficient pressure being applied to bring the surface flat down on to the work, an indentation is made under a load of 20 grammes. Professor Hanemann and his collaborators finding this, and similar instruments, difficult to handle, particularly in centering the indentation under the microscope, devised an arrangement in which the mechanical and optical components are combined in a single instrument.

The Hanemann micro-hardness tester has a front lens of glass in which the diamond, 0.8 mm. in diameter, is mounted. To avoid optical distortion, a lens system with homogeneous immersion is used. The possibility of using a diamond lens has been investigated, but no immersion fluid suitable for the high refractive index of the diamond is available. Other gem stones, approaching the diamond in hardness, could not be used, and the combined glass and diamond arrangement was finally adopted. The instrument incorporates arrangements for measuring the applied load. The Knoop "sensitive" pyramidal diamond point† produces an indentation of oblong shape. It is particularly useful when indentations are used for measuring wear. In this application, after initial measurement of the indentation, the part is put into service. After a specified time, the indentation is measured again, the reduction in area giving a factor from which the wear can be determined.

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* Hanemann and Bernhardt, Zeits. f. Metallkunde, vol. 32, page 35 (1940).

† U. S. A. Patent 2,091,995. See Engineering, vol. 151, page 87 (1941).

Scratching Diamonds.

Scratching by means of a diamond point may be used in measuring and recording instruments, the records produced being examined by means of a microscope or projection apparatus. The diamond point has great durability and produces finer and more uniform grooves than can be obtained in any other way. The relations between load and scratch width and scratch resistance are shown in Figure 9. The records are magnified from 100 to 500 diameters for reading the results. The accuracy of the method is dependent upon the precision with which the curves can be read. A recording instrument* employing the method is illustrated in Figure 10. The housing *a* carries a fixed spindle *b* on which the drum *c* is slowly rotated by a worm gear. The cylinder *d* of glass, or other suitable material, on which the record is made, is carried by the drum *c*. The whole instrument is very small, the drum being only about 1 inch in diameter. The scratching diamond *e* is carried at the end of a light tube, which is given an approximately parallel motion by a double-link arrangement. The outer end of the tube is connected to the apparatus, the movement of which is to be recorded. A separate diamond is provided for tracing the base line. Both diamonds can be lifted out of contact when the glass cylinder is being changed; the pressure they exert is controlled and adjusted by a leaf spring. The external dimensions of the complete instrument are 1 9/16 inch by 1 9/16 inch by 1 3/8 inch; it weighs 4 3/4 ounces. The instrument can be applied for measuring tension, pressure, torque and acceleration, and owing to its very low inertia has great accuracy. For aero-engine work, a special form has been devised with which revolutions over a period of 200 hours can be recorded on a helically-rotating glass cylinder.

Surface-Roughness Testers.

While on the instrument just described, it is essential that a scratch should be made, although so fine that it can only be seen under a high magnification, in surface-roughness testers a scratch should be avoided,† otherwise the recording point would not accurately follow the surface contour. A definite standard has not yet been established in the measurement of the surface roughness of machined parts. The design of the tracer point, although a minor part of the whole problem, does not seem to have been given the attention it deserves. The radius of the point, even if very small, affects the curve reproduced. In the case of the Brush Surface Analyzer,‡ a sapphire point with a radius of only 0.0005 inch is used, but it is necessary to consider how long such a fine point will last before wear occurs. With diamonds it might be possible to produce a genuine sharp edge, but this would cause a slight scratch even under the minimum load. A proper balance has to be obtained between the deformation of the curve caused by a radius and the scoring caused by a sharp point. It is not known if this has been taken into account in practice, but it is not dealt with in the numerous publications on the subject.

Optical Use.

The high refractive index of the diamond, far higher than that of any other known liquid or solid substance, seems to recommend it for high

* Archiv. Technisches Messen, Munich, November and December, 1938.

† Boston and Gilbert, Mechanical Engineering, November, 1940, page 785; also Industrial Diamond Review, No. 8, page 50, 1941.

‡ See Engineering, vol. 151, page 356 (1941).

magnifications and particularly for lenses of small size. Obviously a diamond lens requires a smaller curvature than a glass lens of the same power. A special advantage of such lenses is that they are not easily affected by dust and dirt, and need not be so carefully cleaned as normal lenses. As only diamonds of the clearest water could be used, the cost would be high, and in many cases prohibitive. The grinding of such lenses, however, would not seem to present great difficulties. I. Pike and B. W. Anderson, of the Mineralogical Institute have designed a refractometer in which a diamond is utilized as the material for a prism. The size of the stone before cutting was 6.6 carats, the finished size being 2.5 carats. The refractive index is between 2.41 and 2.45.

SCIENCE IN THE DEFENSE PROGRAM.—The origin and purposes of the National Defense Research Council are described in this paper by Frank B. Jewett, presented at the National Defense Session of the Annual Meeting of the American Society of Mechanical Engineers, held in New York City last December. Mr. Jewett is President of the National Academy of Sciences. His paper is copied from the January, 1942, issue of Mechanical Engineering.

For fifteen years following the first World War there were frequent articles on the probable role of science in future warfare. While this was quite natural in view of the part played by the airplane, the tank, and lethal gas in the titanic struggle of 1914-1918, the articles in the main evoked interest rather than concerted action directed toward full employment of science in preparation for more widespread and more deadly warfare.

Despite the fact that the decade and a half following the war was a period of the most productive activity in fundamental science research and of intense effort to apply old and new knowledge promptly in industry, this *laissez-faire* attitude in the military sector was largely a reflection of men's attitude generally toward war. The weariness of the struggle and the distaste for carnage and destruction, coupled with a naive faith that men had learned finally the lesson of war's futility, gave rise to the era of small appropriations to the military, to disarmament conferences, and to the League of Nations and similar efforts to organize the world for a settlement of international controversies by reasonable methods rather than by recourse to mass murder.

Peace Efforts of 1920's Retarded Defense Science.

In the United States particularly, the decade of the 1920's saw this carried to the extreme. Warships were taken to sea and sunk or were laid up and the Army was reduced to the status of a moderate-sized police force—a force so small and scattered that no really effective training or development of radically new implements could be had. Appropriations were cut to the irreducible minimum of maintaining a national agency which the country would have liked to abolish entirely had it quite dared. In this atmosphere and under these handicaps it is to the credit of the Army and Navy that they did as well as they did. There was little money to spend on development and less still for research to produce entirely new instruments of war.

When the storm clouds of another world war began to form in the middle 1930's, the volume of articles on the place and importance of modern science in warfare increased enormously in both the scientific and lay press. So, too, did discussion of the need for insuring that scientific and technical men

should be utilized in the fields of their competence and not inducted indiscriminately into the combat services where men of less specialized training could serve equally well.

So far as lay discussion was concerned, it was largely emotional, frequently ill-informed, and sometimes fantastic. Naturally, discussion among technical people was more realistic, but on the whole was mainly related to applying newly acquired knowledge and techniques to the improvement of existing military implements. The idea of organizing scientific research on a huge industrial scale, where the ultimate end of "all-out-war" was the industry to be served, was slow to emerge.

Probably the most difficult hurdle every industry has had to get over in the effective introduction of scientific research as a powerful tool in its operation has been to realize that the most profitable research is that which is carried on with the least restraint imposed by current practice. Practice can be adapted to radically new ideas, but radical ideas rarely, if ever, evolve from mere improvements in current practice.

Research in military matters is no exception. War being a very ancient art, military men are on the whole extremely conservative as to new tools. Like doctors, long experience has made them cautious and with possibly a more than ordinary tendency to impose on a research project requirements of current practice which, in fact, hamper rather than help. Against this tendency is the fact that they are quick to adopt the radically new once its utility is demonstrated. War more than any other of man's activities puts a high premium on being in the lead.

As soon as war in Europe on a vast scale was seen to be imminent, the nations there commenced frantically to mobilize and organize their scientific and technical men and resources, and to establish effective liaison between them and the combat services. For more than a year after this movement was in full swing across the Atlantic, our aloofness from the struggle and our ardent desire to keep from being sucked into the tragic maelstrom operated to prevent any effective step in the direction of mobilizing our vast scientific resources for total war. The military services endeavored to strengthen their scientific branches and here and there enlisted the aid of civilian science. They were hampered by inadequate funds, by the pattern of years of a starved organization imposed by an anti-war philosophy, and by the fact that civilian sciences, both fundamental and applied, were built up on a basis of operation in a slow-moving peace economy. The latter had no machinery for marshaling its forces for war and, in the main, it knew little of war's requirements and frequently preferred to follow the courses it understood and liked.

National Academy of Sciences Mobilizes Science.

But about two years ago it became apparent to a few individuals that the *laissez-faire* approach to the mobilization of science ought to be abandoned in favor of a more direct and forceful organizational approach. At that time there existed certain technical groups and associations which, on the one hand, called for strengthening, and on the other were of suggestive value in the search for a suitable organizational setup. I have already remarked upon the scattered technical groups and laboratories within the Army and Navy which over the years had been doing commendable work, but had been given insufficient funds and encouragement. It was, of course, obvious that as the tension of the emergency increased, the responsibilities placed upon these technical groups would mount with a resultant need to augment their personnel, but it was equally apparent that they could not be expected to carry the full load of scientific development and adaptation.

Civilian participation in one way or another in the solution of military problems has come to be taken for granted. It was first given official recognition in the United States when the National Academy of Sciences was incorporated in 1863 by an act of Congress. The charter of the Academy requires that whenever called upon by any department of the government, it shall investigate, examine, experiment, and report upon any subject of science or art, the actual expenses of such investigations, experiments, and reports to be paid from appropriations which may be made for the purpose, but the Academy shall receive no compensation whatever for any services to the government. The Academy is, therefore, recognized as a continuing official adviser to the federal government and it must attempt to answer such questions of a scientific or technical nature as are officially submitted to it by members of government departments. A permanent channel of communication was thus created, but power to initiate traffic over it resides with the government and no auxiliary machinery was created whereby the Academy or any other civilian agency might take the initiative in bringing before the government matters of scientific importance.

National Research Council and N.A.C.A.

Less than a year prior to the entry of the United States into the first World War, another step was taken designed to facilitate the use of the channel of communication between government and the National Academy. In 1916 the National Research Council was created by President Wilson, and a little later was to play a part in focusing civilian effort on the military problems then arising. The National Research Council was, and is today, a subsidiary of the National Academy of Sciences and, like the Academy, is largely an advisory body only and awaits the assignment of problems by one or another branch of the government before it can go seriously to work. Moreover, the Council, like the Academy, is not in possession of free money, a corporate laboratory, and other research facilities and is, therefore, not well constituted to conduct research work on any extensive scale.

We turn our attention, therefore, to another agency contemporaneous with the National Research Council, which was created for the express purpose of establishing cooperative effort between military and civilian groups, and which was provided by Congress with funds necessary to create research facilities and to operate them when once created. This agency is the National Advisory Committee for Aeronautics, commonly known as the N.A.C.A. The law which created the committee provides that it shall "supervise and direct scientific study of the problems of flight, with a view to their practical solution," and also "direct and conduct research and experiment in aeronautics." The committee is composed of fifteen members, including two representatives each of the War and Navy Departments. Throughout its more than twenty-five years of existence, the N.A.C.A. has given ample testimony of the fruitfulness of cooperation between military and civilian groups, and moreover has provided a prototype as to an organizational arrangement for effecting such cooperative effort successfully.

When, some two years ago, the group to whom I have already referred became convinced that broader participation by civilian scientists in the whole military program was likely to be essential, they regarded the N.A.C.A. as typifying the sort of organization they would like to see created. A plan was therefore drawn up envisaging a committee composed in part of civilian scientists and in part of Army and Navy representatives. On the one hand, the committee was charged with a broad study of the materials of warfare and, on the other, it would recommend and, if possible, initiate such research as they believed to be in the national interest.

The N.A.C.A. was created in 1915 by an act of Congress. The somewhat duplicative plan just referred to was submitted to President Roosevelt for such action as he saw fit to take, be it to recommend legislation or to pursue some other course. The proposal appealed to him, with the result that he decided to create the committee by executive order. This order established the committee as a division under the Office for Emergency Management and confers upon them power to take the initiative in many scientific matters which they believed to have military significance. It also directed the committee to develop broad and coordinated plans for the conduct of scientific research in the defense program, in collaboration with the War and Navy departments; to review existing scientific-research programs formulated by these departments, as well as other agencies of the government; and advise them with respect to the relationship of their proposed activities to the total research program. Moreover, and this is especially important, the order directs them to initiate and support scientific research on the mechanisms and devices of warfare with the object of improving present ones, and creating new ones.

The order contemplated that the committee would not operate in the field already assigned to N.A.C.A. nor in the advisory field of the National Academy of Sciences and National Research Council. Parenthetically it might be noted that in this latter field the Academy and Council are currently engaged on advisory work for government for which the out-of-pocket expenses alone are at the rate of much more than $1,000,000 a year.

National Research Defense Committee Organized in 1940.

Thus, in June, 1940, the National Defense Research Committee, more familiarly known as the N.D.R.C., was born. It was constituted of eight members, two of these being high-ranking men from the Army and Navy, respectively, five more being civilians well known for their experience in organizing and directing both fundamental and applied scientific research, and, as an eighth member, the Commissioner of Patents.

The Executive order creating the N.D.R.C. omitted any reference to the biological sciences, and in particular to the medical sciences. However, during its first year of operation, experience accumulated to the effect that a broader program of attack would not only be useful but was, in reality, urgently demanded. This realization prompted a second approach to President Roosevelt, with the result that in June, 1941, he created two new functional groups. One of these was the Committee on Medical Research, to explore its indicated territory in the same manner that the N.D.R.C. had been exploring the physical sciences. Then, over and above both the N.D.R.C. and the Committee on Medical Research, there was placed the Office of Scientific Research and Development, usually referred to as O.S.R.D. This latter office was placed in charge of Dr. Vannevar Bush, who until then had been chairman of the N.D.R.C. President Conant of Harvard was then made chairman of the N.D.R.C. and Dr. Richards of the Medical School of the University of Pennsylvania was made chairman of the C.M.R.

In order to insure complete coordination of civilian and military research and development, Dr. Bush, as director of O.S.R.D., was provided with an advisory council consisting of the chairmen of N.D.R.C., C.M.R., and N.A.C.A.; the coordinator of Naval research and the special assistant to the Secretary of War performing a somewhat similar function in that service.

The executive orders creating these various committees naturally had to leave indeterminate the question of financial support. They are all subsidiary to the Office for Emergency Management and, like this office, must look to Congress for the necessary operating appropriation. Thus far the appropri-

ations, while not munificent, have been adequate. During its first year of existence the N.D.R.C. authorized research projects which totaled about ten million dollars. At the beginning of its second year it was granted another ten millions and this was recently augmented by several millions more. To be more specific, the O.S.R.D. during its first year of existence, will guide the expenditure of about twenty millions throughout the whole scientific field.

I should now like to take a few minutes of your time to explain the manner in which the expenditure of these funds is initiated and supervised. To begin with, let me point out that the work of the N.D.R.C. is divided into four major departments: Division A, of which Prof. R. C. Tolman of California Institute of Technology is chairman, deals with armor, bombs, and ordnance, in general; Prof. Roger Adams of the University of Illinois heads Division B on Chemistry; Division C deals with transportation and communication, and submarine warfare, and I am its chairman; finally, Division D, which deals with instruments and numerous miscellaneous projects difficult to catalog, is headed by President Compton of Massachusetts Institute of Technology.

To expedite discussions, surveys, and the general handling of the work, a further breakdown has been found desirable, the result being that each division comprises several so-called sections. Division B on chemistry, under Professor Adams, is divided into thirty-one sections—which stands to date as a sort of record.

How N.D.R.C. Functions.

The work of a section is entrusted to a section chairman, who in turn calls to his aid certain individuals who become permanent members of his sectional committee and who are known technically as members. Then there are others who may be asked to render advice and assistance from time to time and hence are called consultants. Members and consultants are officially appointed by the chairman of the N.D.R.C. and are designated only after official clearance by the Army and Navy Intelligence and the F.B.I. Full consideration is therefore given to the basic requirements of the military services as regards the confidential handling of their problems.

Neither the five civilian members of the N.D.R.C. itself nor any of the section chairmen, members, or consultants are paid from public funds. Without exception, they are loaned to the government by their employing organizations and frequently the loan is complete, the work being so voluminous and detailed as to require a man's full time. Thus, when I tell you that about 500 of the leading scientists of the country are encompassed in the present N.D.R.C. organization, you will see that the federal government and even the forgotten taxpayer are getting a lot of valuable consulting talent free of charge.

So far as I have now outlined it the functioning of the N.D.R.C. requires no public money except a very small amount for paid office assistants together with the traveling expenses of members and consultants. For the most part members and consultants do not carry on the research and development projects which the N.D.R.C. decides to promote—their duties are advisory and administrative. They formulate the problems which they believe it important to have undertaken, and then arrange with various scientific institutions to carry on the work. It is this last step which brings in the need for considerable sums of money. For instance, a project assigned to a particular university may require the full time of several of its faculty together with that of numerous younger men hired specifically for the work in hand.

The number of such projects now approved and, for the most part, contracted out to universities and industrial research laboratories stands around 550 while the number of contracting institutions is over 100; and when it is stated that the total value of the projects thus far determined upon is upward of twenty million dollars, you will realize at once that the monetary resources of the scientific world would not be adequate to conduct the program on a gratuitous basis. The contracts vary all the way from those involving a few hundred dollars to those calling for two to three hundred thousand dollars per month.

The question is frequently asked as to how many technical people have been drawn into the civilian defense effort which the N.D.R.C. directs, but obviously this is quite difficult to estimate, let alone to enumerate in detail. I have already mentioned that there are about 500 scientists in the N.D.R.C. organization serving as members, consultants, etc. It seems likely that somewhere between two and three thousand scientists are at work on defense projects as employees of contractors with about an equal number of less highly skilled individuals assisting them as laboratory assistants, technicians, etc. Then, if the situation which I know to exist at the Bell Telephone Laboratories is to be taken as a criterion, we must add to this scientific group another very considerable array of technical people who call themselves engineers as opposed to physicists and chemists—an array which if enumerated would no doubt total four to five thousand.

Recent figures from the Bell Telephone Laboratories might be of interest as perhaps typifying the situation found in a number of industrial laboratories which are fulfilling defense contracts, some for the N.D.R.C. and some directly for the Army and Navy. A rough count shows that about 600 of our technical staff are now engaged directly on a full-time basis on defense projects. When I sav that they are "engaged directly" on defense projects, I am excluding those who by circumstances arising out of the defense program have been forced to devote themselves to such problems as the finding of substitute materials and the engineering of emergency telephone projects.

"No Profit" Feature of N.D.R.C. Operation.

Another aspect of the N.D.R.C. plan of operation which I should like to stress is its "no profit" feature. This applies alike to contractors and to employees of contractors. Perhaps this point can be brought out most clearly by reference to a specific situation. The University of California is acting as a contractor to the N.D.R.C. on a large project which involves an annual expenditure of around one million dollars. Certain members of the California faculty are employed on a full-time basis on the project and in switching from teaching to defense work have incurred no change in rates of pay. The university has also hired from other faculties certain individuals to augment the defense staff and they, likewise, have gone over without changes of salary, although a payment is made to compensate for the cost of moving in the case of both single and married men. It is also stipulated explicitly that the university, as contractor, will derive no monetary profit from the work and the same requirement is exacted of industrial laboratories and other types of contractors.

The "no-profit no-loss" proposition has involved the adoption of certain more or less arbitrary but seemingly equitable rules of accounting. Thus, a university is usually allowed an overhead payment amounting to 50 per cent of the salaries which it pays to its members employed on a defense project. Similarly, an industrial laboratory, by virtue of the fact that it has to operate with commercial capital and is subjected to a variety of forms of

taxation from which the university is exempt as well as other expenses, is allowed an overhead of 100 per cent of the salary item.

I suppose it depends upon one's point of view as to whether the effort I have just outlined appears large or small. On the one hand, it seems fairly certain that it is only a beginning and must expand further. On the other hand, it is certainly large already when contrasted with any civilian effort which was able to assert itself during the last war. And looking back to the situation which existed a quarter of a century ago, it is difficult to understand why the then available civilian agencies were not unleashed to an extent commensurate with their obvious capabilities. True, the National Research Council was created to assist with the solution of defense problems, but it was, as I have pointed out, in the position of a doctor waiting for clients; it could not adopt the attitude of an aggressive salesman and initiate attacks on what it regarded to be important military problems. Hence we can declare that as regards organization notable progress has been made.

As to future expansion of our civilian defense effort, it is becoming increasingly essential to bear in mind the potential shortage of trained personnel. Without insinuating anything as to guilt, the chemists declare that this is a physicist's war. With about equal justice one might say that it is a mathematician's war. The visible supply of both physicists and mathematicians has dwindled to near the vanishing point, consistent with the maintenance of anything like adequate teaching staffs in our universities. If this civilian-defense effort is to expand, and such indeed now seems imperative, the limiting factor may therefore be a shortage of highly trained individuals and not a shortage of financial aid.

This leads me to state a few general observations concerning the past and future of our work. It is quite apparent that to date the burden of N.D.R.C. contracts bears much more heavily upon some institutions than upon others. At the outset this has necessarily been the case. While serious attention has at all times been given to the subdivision of projects so that they could be farmed out as widely as possible, a limit is frequently reached beyond which it is not practicable to go in the matter of division. In many cases, no division at all could be entertained, a situation that has given rise to a few large contractors, of which I cited the University of California as an example.

In the assignment of the early contracts it has been natural, in fact essential, to lean heavily upon those institutions, both academic and industrial, which for one reason or another have been peculiarly fitted to transfer quickly from peacetime to wartime problems. This has been done with a view to conserving time. But the stages of the program to follow will doubtless involve a broader survey of the situation to find locations where new problems can be lodged with a minimum of interference to essential defense work and teaching now in progress. In this survey a guiding principle will be to utilize men and facilities in situ whenever possible, thus preserving the "going value" of groups who are accustomed to working together. In the face of crises, the human tendency is usually to do the reverse, it being so easy for central agencies to ignore established but not well-known organizations, and attempt to cope with an emergency by calling workers from right and left to some new location. As a matter of fact, this tendency was beginning to make an appearance even as long as two years ago when the fundamental plan of the N.D.R.C. was under discussion. Had the tide then setting in been allowed to run on for some months unimpeded, the result would inevitably have been a literal army of uprooted scientists in Washington and other central points. sitting around idly waiting for vast amounts of research equipment which had been placed

on order, but was not much nearer materialization than that, to be installed in hastily constructed laboratories. This would have been the easy and disastrous way. Fortunately, the creation of the N.D.R.C. came in time to stem such a tide.

Another present problem, and it is the last with which I shall trouble you, is one which by its existence supplies evidence that real progress has already been made in some of the research programs thus far initiated. It has to do with shortening the time gap between proved laboratory-research results and the stage where mass production can be undertaken. Some of the laboratory results already achieved hold such promise that every day which intervenes before their widespread utilization becomes a serious matter. Obviously the problems to be met here cover a wide range of equipment and materials—as wide as that marked out by the scientific results themselves—and since they involve large-scale manufacture, the whole plan must be carefully worked out with other official agencies, particularly the Office of Production Management. I am sure, however, that we are prepared to meet and solve these problems, and rather than be concerned with the difficulty of making progress along this avenue, I think all who are guiding the work of the N.D.R.C. would exclaim to the ranks of scientists and technicians, "Bring on your results, the more the better, and we will guarantee them a speedy passage to the firing line!"

THE ROTATING BOILER TURBINE.—This abstract of R. Nott's article is taken from Transactions of the Institution of Marine Engineers, January, 1942. Mr. Nott's complete article was published in Boiler House Review, October, 1941.

Further developments are reported from the Continent in the rotating boiler turbine invented by the German engineer F. Hüttner, who has now constructed a unit of 100 Kw. capacity (Figure 12) with a multi-stage turbine, jet condenser, air pre-heater and forced-draught fan, as well as regenerative feed heating in conjunction with inter-stage separation of water formed during expansion. This relatively complex machine has virtually no external auxiliaries or pipes and there is a total absence of reciprocating mechanism, but provision must be made for cooling the condenser water outside the machine by means of orthodox surface coolers. The speed of the turbine is controlled by regulating the fuel supply and the response is claimed to be about equal to that of a petrol engine, this being due to the very small heat- and water-containing masses present. The full-load speed of the turbine is 10,000 RPM., and of the boiler 2000 RPM. Both liquid and gaseous fuels may be used in the Hüttner turbine and both are said to have been tried. Solid fuels have been ruled out on the ground of excessive wear of the heating surfaces due to the abrasive action of solid particles in the combustion gases, but the suggestion is made to couple the rotating boiler turbine with a gas producer and to pass the gas generated, after purification, into the rotating boiler, just as with gaseous fuel. The scheme adopted for oil burning is shown in Figure 15. The oil fuel is admitted near the axis of rotation, is broken up into a fine spray by a revolving atomizer attached to the heating-surface assembly, and driven thence into the mixing chamber through a series of short heater tubes. As regards the specific weight of the rotating heating surfaces, it is estimated that for a steaming rate of about 50 lb./ft.^{2}-hr. at 510 lb./in.^{2} pressure and a steam consumption of 11 lb./h.p.-hr., which is to be expected from a 1000-

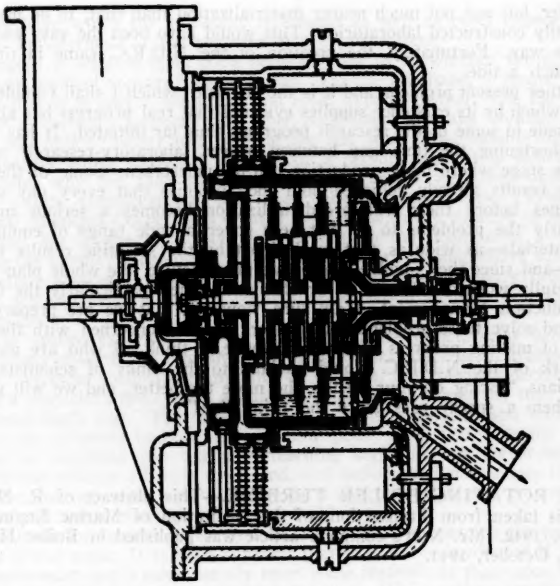

FIGURE 12.—HUTTNER ROTARY BOILER TURBINE UNIT FOR 100 KW. OUTPUT.

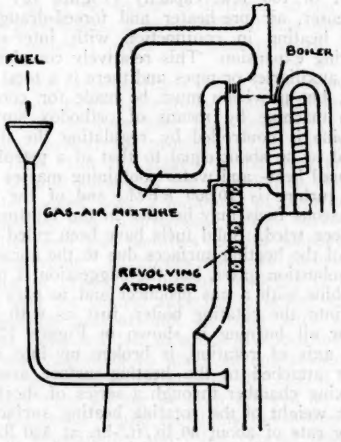

FIGURE 15.—EXPERIMENTAL RIG FOR OIL FIRING.

HP. machine, this should amount to 0.22 lb./h.p., assuming double-sided finning and 1 mm. wall thickness of the U-tubes. The total specific weight of a 500-HP. rotating boiler would be about 2.2 lb./HP., and of a 2000-HP. machine 1.65 lb./HP. The overall dimensions should be similar to those of an electric motor developing the same power. No information is given, however, regarding the class of materials considered in calculating these figures or to what extent light alloys would figure in the construction. Great difficulty is not expected in balancing the boiler for a large machine, because the U-tube assembly is quite symmetrical and the water levels also maintain symmetry by virtue of centrifugal force. However, one feels bound to speculate on the possible deleterious effect of alternate expansion and contraction, caused during starting and stopping, of the materials which go to form the boiler. Possible snags present themselves in the construction of such a boiler suitable for working at high pressures on account of the close spacing and finning of the U-tubes. Superheating of the steam before entry into the turbine would seem to offer a profitable field of research, but since this would inevitably give rise to completely new thermodynamic conditions with consequent need for much alteration in design, coupled with the extreme difficulty of providing the U-tube block with a superheater in any form, the gain that might result therefrom would appear to be neutralized by the technical and economic disadvantages incurred. Nevertheless, the rotating boiler turbine has much to offer for marine service in the lower powers, where a combination of low weight, compactness and good thermal efficiency is called for.

FROM THE INSPECTOR'S POINT OF VIEW.—This item is reprinted from Engineering (London), December 19, 1941.

No true Briton likes an inspector. There is, for example, nothing so exasperating as being asked to produce one's ticket when travelling first class—especially if it is a third-class ticket. The Inspector of Naval Ordnance therefore starts his career at a considerable discount for, if inspectors as a class are unpopular, Government inspectors are anathema to all manufacturers. The sturdy independence which raises a man from foremanship in a pot and pan factory to the managing directorship of a vast organization is naturally affronted by the knowledge that the Government inspector has considerable power to interfere with production by insisting on a higher standard of excellence than the manufacturer himself considers to be necessary. It is no uncommon thing to hear it said that, "after all, it's only got to work once," when discussion is taking place about the finish required on something that is to be fired at the enemy; and the retort must inevitably be "Yes, but it must work that time."

An individual who joins the Inspection Department in time of war must indeed walk warily, for he will be shot at from all angles and, if he succumbs to the sniper's bullet but once, he will find it difficult to come to life again. Business men are shrewd judges of character and ability, and are not renowned for changing their opinions. It is very necessary, therefore, to make a good impression, when first visiting a factory and to make it clear to the "powers that be" there that the inspector has only one aim, and that is to ensure that the weapons being manufactured will leave the works 100 per cent efficient. He, by virtue of his office, is in possession of knowledge that the manufacturer will not usually have—knowledge of the conditions under which the weapons are stored before and during use. If he can

make it clear that he is there to help in the avoidance of mistakes and failures, and not to act as a damper of enthusiasm and output, then he will not suffer the bitter experience of being quietly sidetracked by the manufacturer telephoning someone higher up in the Department wherever there is a point at issue between them.

The ideal inspector must be able to talk to manufacturers in their own language, whatever it is (and it will be appreciated that modern weapons include nearly every trade in their production, from plastics to the heavy steel industries). He must be able to express himself clearly, both verbally and on paper, and to hold the balance fairly between the natural tendencies of his own staff to abuse the manufacturer, and vice versa. He must be possessed of a roving eye and the ability or luck to drop on faults that have escaped his underlings' vigilance. He should have a thorough grounding in elementary engineering, physics, and chemistry; and, above all, he must have abounding commonsense, good manners, tact, and understanding. If, to all these virtues, a sense of humor be added, he will indeed accord with Kipling's specification of a man.

Such individuals, alas, do not grow on bushes, nor do they languish without employment for years waiting for a World War to give them a poorly-paid post in Government employ; they are not likely, therefore, to be found in the Inspection Department. The perfect inspector is to be found in Heaven only. Fortunately, much can be done by lesser mortals, whatever their qualifications, if they are determined to help the war effort first, last, and at all times. With this simple thought as a guide, it will be possible to avoid the pitfalls that lie on all sides. There is the danger of making a god of production for production's sake, of being stampeded into sanctioning a departure from design by the urgency of the demand for the weapon, without considering to the full the implications of this departure. He is a strong man indeed who will stop an assembly line employing a thousand men because the products of their work are unsatisfactory; but this may have to be done, whatever the effect on the subsequent relations between the management and the Inspection Department.

There is the danger, also, of becoming soured by the experience of man's fallibility. When the inspector discovers that he is regarded as "fair game" by the workers—that anything put past him scores one for the home side—he will become suspicious of every man, and may develop the outlook of what Lord Donegall has described as "an inverted Micawber—waiting for something to turn down." He is a paragon who can steer an even course between the Scylla of over-friendliness with the manufacturer and the Charybdis of blind insistence on the written word.

The necessity for such virtues would not be so vital if circumstances were different from those which prevail at the present time. If the mass-production of weapons had been planned in plenty of time, so that the weapons had been fully proved before manufacture was commenced, if the gauge production of this country were able to satisfy the demands made upon it, there would be little need for anything but an automaton, fully provided with perfect drawings and gauges for all components. Things, however, are not like that. In war there is no time to make up ground lost in the idle days of peace. The fighting Services demand a number of weapons; there is no time to dally while the job is tested and proved to be a "production job"—the order is placed, and manufacture begins. Sometimes it is found that there are discrepancies and errors in drawings and specifications, that the designer has not fully considered the manufacturer's angle and that the gauges ordered for inspection purposes will not be ready until after the contract is completed. All these and many other problems are thrust at the inspector by insistent manufacturers, who must keep the

wheels of their factories turning, and who would rather do anything than commit that most heinous of crimes—"holding up production." Decisions must be made, if not by the local man, by the designer himself, who is loth to be stampeded. The inspector must be on the job, coaxing decisions out of his superiors and keeping the manufacturer informed and encouraged. But who encourages the inspector?

It is indeed a thankless task, the results of which can never be gauged. The goal that the inspector must strive to reach is that of hearing no complaints from the men who use the weapons at sea, and this, alas, can never be attained. There are days when reports reach him of stores that failed—it may be only a small percentage of the total number, but there will be more said about the few that fail than about the nameless many that function; and so the unhappy inspector can achieve no satisfaction. Never does he hear from sea that such-and-such a store is a howling success, nor do those in authority feel it necessary to encourage him by accounts of successes. There should be no failures; but there cannot be more than 100 per cent success, and so the balance sheet will always show a deficit.

So give pause for a split second, you fighting men, when next a weapon fails, and remember that the fallibility of human nature is such that perfection can never be obtained. Let there be appreciation of the 999 successes; and not too much emphasis on the one that failed; and, if you have a friend in the Inspection Department—drop him a line and tell him how you use the weapons that he tries so hard to give to you, accurate in performance and, above all, safe to handle. We think of you at all times—think of us a little, and forgive us our trespasses.

BOOK REVIEW.

PRACTICAL MARINE DIESEL ENGINEERING, By R. L. Ford, which was reviewed in the February, 1942, issue of the Journal, is distributed in the United States, solely by Interscience Publishers, Inc., New York, N. Y.

THE RADIO AMATEURS' HANDBOOK—Special Defense Edition. This volume has been issued by the American Radio Relay League as part of its contribution to National defense. The special edition is published in the same form as the annual edition which has appeared since 1926. The book is intended as a text for defense training courses. It has retained everything from the 1942 edition which seems to be useful for the purpose intended, but has had eliminated those portions which, though essential to a thorough knowledge of the radio art, can be omitted from a course of training which must obtain results in a minimum of time.

It appears to be a thoroughly practical book.

Published by the American Radio Relay League. Price $1.00.

THE HIGH-SPEED INTERNAL-COMBUSTION ENGINE, By Harry R. Ricardo, F.R.S., Revised By H. S. Glyde, B. Sc. (Eng.) London, A.C.G.I.

This book which first appeared in 1923 has now been published in its third edition. The worth of the work and the reputation of its author requires no comment. This revision has been prepared by Mr. Glyde due to the fact that the author has become

too involved in war work to leave him sufficient time to undertake the labor himself.

The revision has retained as much as possible of the original, the greater part of which dealt with principles of engine design and fuel behavior which have not changed. New subject matter, to bring the work into step with the developments of the past ten years, has been added regarding the high-speed Diesel engine.

Published in Great Britain by Blachie & Son, Ltd., Glasgow. Distributed in the United States solely by Interscience Publishers, Inc., New York, N. Y.

ASSOCIATION NOTES.

The American Society of Naval Engineers is now carrying on through its third war. It takes little reflection to realize that this war is an engineer's war such as has not been visualized in the past. Much of the facility with which the actual fighting forces of the United States will apply their valor to earn the complete victory for which we are heading will be a reflection of the thoroughness with which the engineer has been laying the groundwork for the past twenty-five years and how well he is applying his advances under the pressure of all out war.

The Society was founded for the advancement of Naval Engineering. It can take pride in its contribution to this purpose during the fifty-four years of its existence. Its principal instrument has been the JOURNAL which has never missed an issue in peace or in war. The JOURNAL furnishes a forum at which naval engineers can present their accomplishments or those of others; and their individual advanced thinking which is the necessary first step of every engineering advance.

Because of the mechanized nature of this war of defense of human principles, the publication of a technical journal meets exceptional difficulties not normally experienced. The JOURNAL's value depends entirely on the merit of the papers which are submitted and accepted for publication. The two new difficulties of the present war are:

First: Practically every active member is now intimately and actively engaged in direct defense work which is so time-consuming that little time for authorship is available, and

Second: National security demands that nothing be published which might be of benefit to the enemy.

Little can be suggested as to how prospective authors can find the necessary time. That must be a matter for the individual to handle. As regards subject matter which meets the qualifications

of furthering the advancement of naval engineering without contribution to the Nazi cause, a few suggestions can be made. It would seem that at least three general classifications of articles will fit the restrictive qualifications. These are:

Naval Engineering History—accomplishments and mistakes of the past have a definite bearing on engineering advance and the field of unpublished engineering history of interest and definite value should be extensive;

Commercial engineering advances which have been the outgrowth of naval engineering progress as well as straight commercial engineering advances which provide food for thought and guidance of the naval engineer; and

Those individual engineering thoughts which in many cases appear to be radical but in a generation or less will become conservative or even antiquated. There should be a large number of these which will tend to keep the JOURNAL at its proper level yet at the same time will require so much development before practical application that little aid to the enemy in his prosecution of the present war will be given.

If the Society is to finish this war with its record of continuous publication unmarred it will be because the members rally to the cause and prepare and submit articles for publication.

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